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EVALUATION OF THE RADIONUCLIDE CONCENTRATIONS IN SOIL AND PLANTS FROM THE 1975 TERRESTRIAL SURVEY OF BIKINI AND ENEU ISLANDS

C. S. Colsher, W. L. Robison, and P. H. Gudiksen

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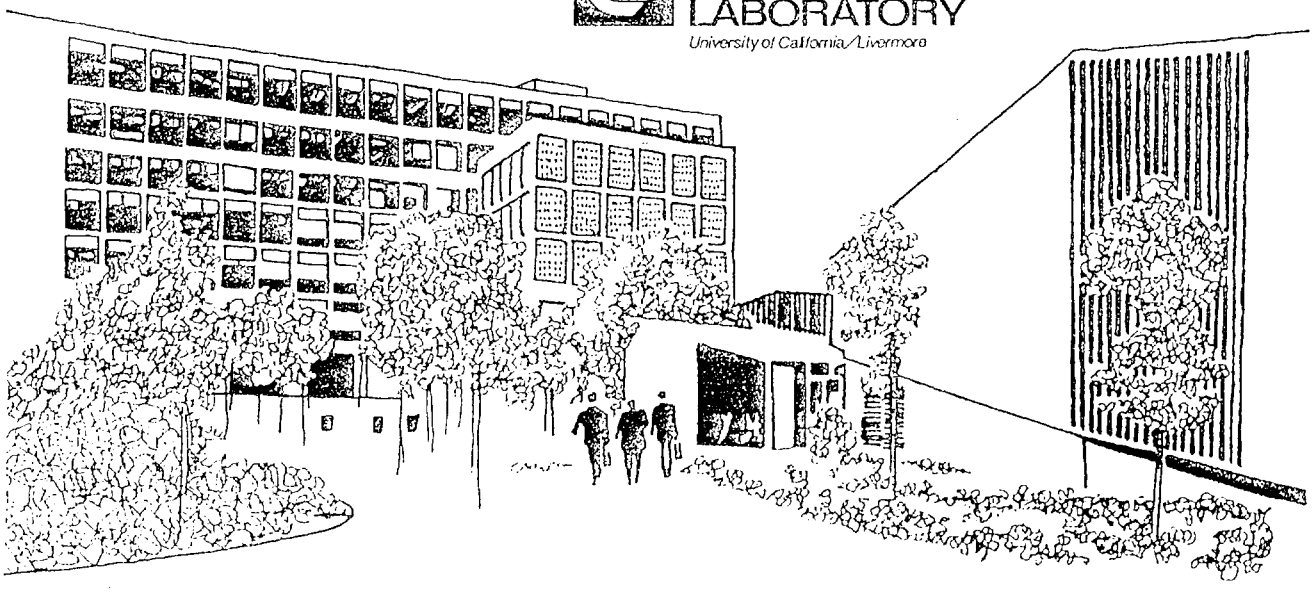

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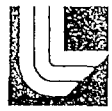

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EVALUATION OF THE RADIONUCLIDE CONCENTRATIONS IN SOIL AND PLANTS FROM THE 1975 TERRESTRIAL SURVEY OF BIKINI AND ENEU ISLANDS

Abstract

In June 1975, personnel from LLL and from other laboratories and agencies conducted a radiological survey of the terrestrial environment of Bikini and Eneu Islands (Bikini Atoll) to evaluate the potential radiation dose to the returning Bikini population. In this report, we present measurements of the radionuclide concentration in soil profiles and in dominant species of edible and nonedible, indicator plants. We also describe the use of these data to derive relationships to predict the plant uptake of radionuclides from soil.

Approximately 620 soil and vegetation samples from Bikini and Eneu Islands were analyzed by Ge(Li) gamma spectrometry and by wet chemistry. The predominant radionuclides in these samples are ^{60}Co, ^{90}Sr, ^{137}Cs, $^{239,240}Pu$, ^{241}Pu, and ^{241}Am. In general, the radionuclide concentrations in soil from Eneu Island and from the four areas of Bikini Island appear to approximate log-normal distributions. The median surface-soil concentrations (pCi/g) of Eneu Island (0.067 for ^{60}Co, 4.1 for ^{90}Sr, 2.9 for ^{137}Cs, 0.25 for $^{239,240}Pu$, and 0.22 for ^{241}Am) are ten times lower than those measured on Bikini Island (0.86 for ^{60}Co, 76 for ^{90}Sr, 43 for ^{137}Cs, 3.0 for $^{239,240}Pu$, and 2.4 for ^{241}Am). We found that radioactivity is unevenly distributed over the surface of these islands and that the distribution of activity with soil depth varies greatly in different parts of the islands. Concentrations in the soil of ^{90}Sr and ^{137}Cs are greater than concentrations of ^{241}Am and $^{239,240}Pu$ which, in turn, are greater than concentrations of ^{60}Co.

To quantitatively evaluate the plant uptake of ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$, we develop soil-plant concentration factors as well as leaf-leaf and fruit-leaf concentration ratios for indicator and edible plant species from the same location. In general, the concentration factors for ^{137}Cs in terrestrial vegetation are greater than those for ^{90}Sr. The concentration factors for both of these nuclides exceed those for $^{239,240}Pu$ by one to two orders of magnitude (10 to 100 times). For ^{90}Sr and $^{239,240}Pu$, nuclide uptake by fruit is less than that by mature leaves; however, the opposite is true for ^{137}Cs. The relative contribution of the individual plant species to the internal dose to man

varies with the nuclide under consideration. Thus, we also describe the use of concentration factors and concentration ratios to predict nuclide concentrations in fruit from those observed in soil or leaves.

Introduction

Since the termination of nuclear testing on Bikini Atoll in 1958, periodic environmental surveys have been conducted to evaluate the radiological status of the atoll. The early surveys of Bikini Atoll as well as the recent survey and assessment at nearby Enewetak Atoll indicate that concentrations of radionuclides in certain terrestrial foods are relatively high, suggesting that the terrestrial foodchain could be a major exposure pathway.[1-4] In June 1975, Bikini Atoll was resurveyed to determine the residual radioactivity in the terrestrial environments of Bikini and Eneu Islands, the two main islands of the atoll (Fig. 1). The 1975 survey included measurement of environmental gamma-ray exposure rates and the collection and analysis of samples of soil, ground water, cistern water, and vegetation for use in assessing the internal dose via various ingestion pathways. (The dose from external gamma exposure and the radionuclide concentrations in cistern and ground water have been previously reported.[5,6])

The longer-lived fission and activation products are the nuclides of primary concern at Bikini Atoll. Previous studies have shown that because of their long half-lives and large inventories, ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$ contribute nearly all the population dose from the terrestrial pathway.[7,8] In this study, our major emphasis is on ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$. However, the results obtained for ^{60}Co and ^{241}Am are also included because ^{60}Co is widely distributed and is present in the marine pathway and because the concentration of ^{241}Am is still increasing slightly due to the decay of ^{241}Pu.

In this report, we describe the results of the soil and vegetation studies of the 1975 survey. We also discuss the use of the data to derive relationships that predict the plant uptake of nuclides from soil on Bikini Atoll. Geometric mean values of ^{60}Co, ^{90}Sr, ^{137}Cs, $^{239,240}Pu$, and ^{241}Am surface-soil concentrations are developed for Eneu Island and for each of the four areas into which Bikini Island was divided. We also

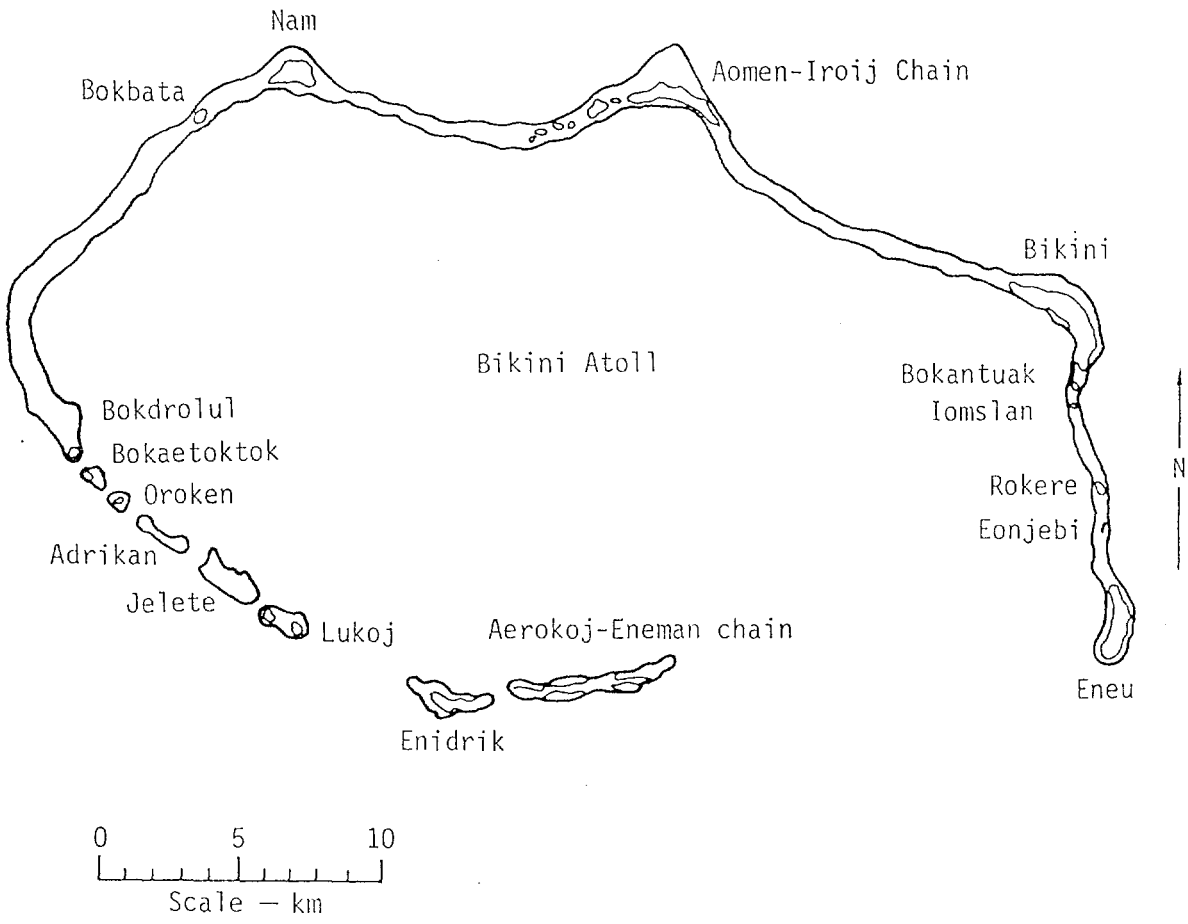

Fig. 1. The Bikini Atoll.

analyzed soil profiles to investigate the distribution of activity with soil depth.

Soil-plant concentration factors and soil-plant regression equations, together with leaf-leaf and leaf-fruit concentration ratios, are calculated for ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$ in edible and indicator plants as well as in soil from the associated sampling site. From our evaluation of these data, a method is developed for predicting the nuclide concentrations in edible plants at a given location from the determined nuclide concentrations in soil at the same location. The predicted nuclide concentrations in edible plants subsequently serve as input data to predict the internal dose from ingested terrestrial foods. This dose assessment is presented in a separate report.[9]

At Bikini Atoll, the uptake by plants of radioactive material from the soil is the principal source of foodchain contamination. Thus, soil is both the convenient and the logical starting point for a prediction of

radionuclide concentration in terrestrial plants. Soil-plant concentration factors or soil-plant regression equations are commonly used for a quantitative comparison of the capacity of different plant species and various plant organs to accumulate radionuclides through soil-root uptake.[10] Prediction of radionuclide uptake by edible plants is needed to convert the measured environmental soil concentrations into the potential dose to man from the soil-plant pathway. Where fruit samples are not available, correlations between the concentrations in leaves and fruit of a particular plant species or between concentrations in leaves of indicator and edible plant species enable us to predict plant uptake from soil.

Methods

ENVIRONMENTAL SAMPLING AND LABORATORY ANALYSIS

The objective of the surface-soil survey was to define the distribution of radioactivity within the soil on Bikini and Eneu Islands. This survey was conducted in a manner similar to that used at Enewetak Atoll.[1] The number of soil samples collected on each island and within specific areas on the island was a function of the anticipated radioactivity levels, the various housing locations under consideration, and the expected living patterns of the future inhabitants. Thus, Eneu Island, because of its low and homogeneous activity levels was sampled less densely than Bikini Island. Bikini Island has elevated and more variable activities and was divided into four distinct areas, each of which could be used for future village sites. Sampling sites were selected by superimposing a rectangular-grid network over an aerial photograph of each island and randomly choosing the grid squares to be sampled within each specific area of interest. The surface-sample locations for the islands are shown in Fig. 2. These samples were taken with a coring tool (a steel pipe, 30 cm^2 in cross-section) to a depth of 15 cm. The surrounding soil was scraped away and a cutting tool (a flat piece of steel) was inserted underneath the cover, freeing the sample.

In addition to the surface-soil sampling program, vegetation and associated soil profiles (soil profiles taken from the same location as the plant) were collected wherever suitable plant species were located on Bikini and Eneu Islands (see Fig. 3, Appendices A and B). Leaves,

fruit, roots, litter, and stems of edible (*Pandanus*, breadfruit, coconut, papaya, banana, and squash) and non-edible indicator (*Scaevola* and *Messerschmidia*) plants were collected when available. We attempted to take at least one soil profile, and preferably as many as three, through the root zone of each sampled plant. In addition to the soil profiles taken through the root zone of sampled vegetation, other soil profiles were collected on a random basis on both Bikini and Eneu Islands. The geographical locations of these profiles are also shown in Fig. 3.

All profile samples were taken from pits dug with a backhoe. After the pit was dug, the sidewalls were carefully cut back a few centimeters to ensure a clean, undisturbed profile. For each profile, 100-cm^2 samples were collected from the sidewall at increments of 5 cm in the upper part and of 10 to 20 cm through the lower part of the profile. Total depth for profile samples varied from 25 to 105 cm.

Vegetation and litter samples were carefully selected and classified by age. For example, collected leaves were classified as young, mature, and senescent. Two ages of litter were readily identifiable and were collected accordingly. However, fruit samples representing different stages of growth were unavailable. All samples were handled separately, placed in plastic bags, and sent to LLL for processing and analysis. All soil and vegetation samples were analyzed both by Ge(Li) gamma spectrosocopy and by wet chemistry for the following radionuclides (see Ref. 12): ^{40}K, ^{55}Fe, ^{60}Co, ^{90}Sr, ^{106}Ru, ^{102m}Rh, ^{110m}Ag, ^{125}Sb, ^{133}Ba, ^{137}Cs, ^{144}Ce, ^{152}Eu, ^{155}Eu, ^{207}Bi, ^{228}Ra, ^{235}U, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{241}Am.

DATA ANALYSIS

The surface-soil (0 to 15 cm) activities appear to approximate log-normal distributions and thus, we calculated geometric means of ^{60}Co, ^{90}Sr, ^{137}Cs, $^{239,240}Pu$, and ^{241}Am concentrations in soil for Eneu Island as a whole and for the four areas of interest on Bikini Island. For each profile collected, we plotted (on semilog paper) the concentrations of the selected nuclides as a function of depth. The profile data were compared in an attempt to characterize the different areas of the islands (see Appendices A and B).

Because they are the major contributors to the dose from ingestion of terrestrial foods (Refs. 1, 7, 8), ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$ were selected for more detailed analysis. We calculated concentration factors for these nuclides from measured

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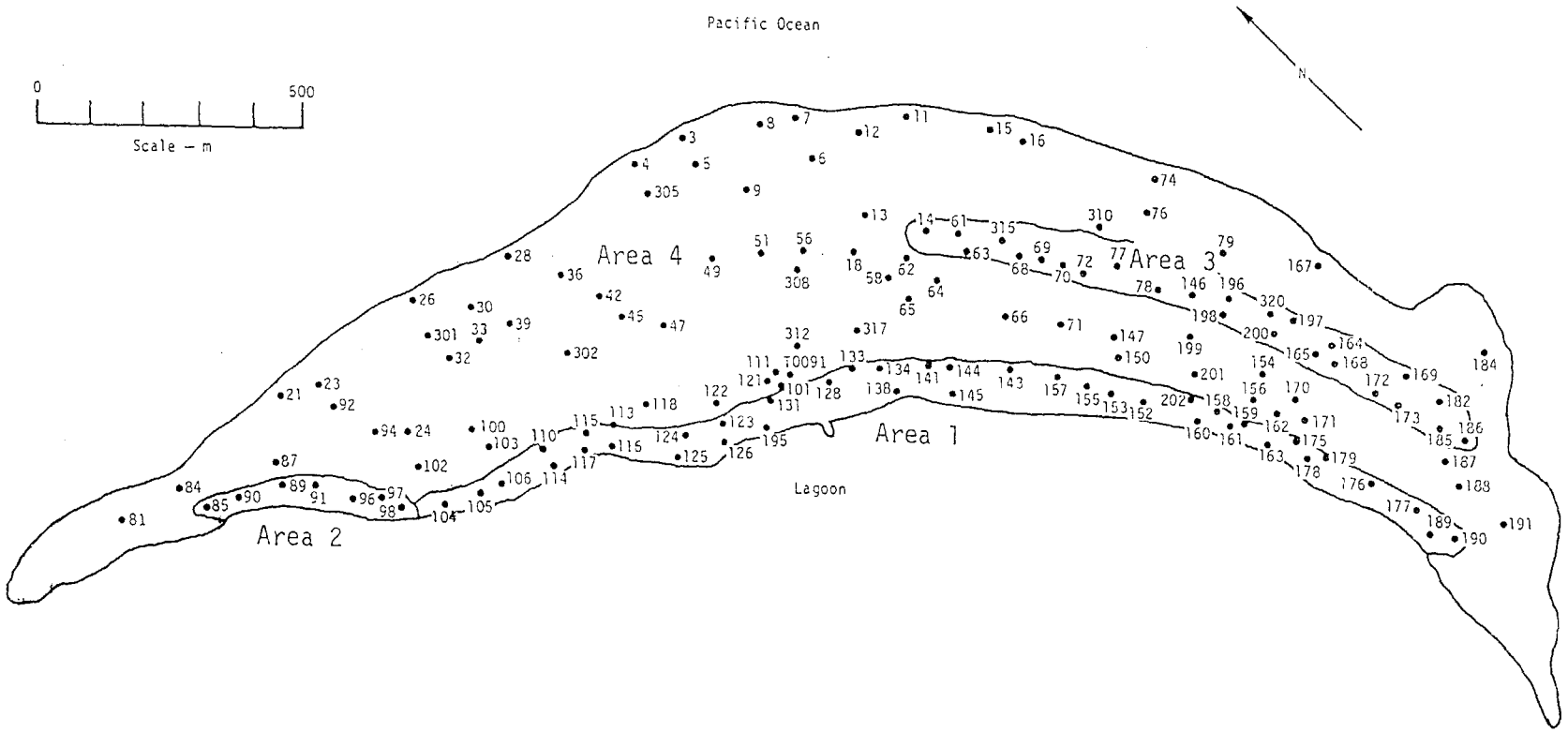

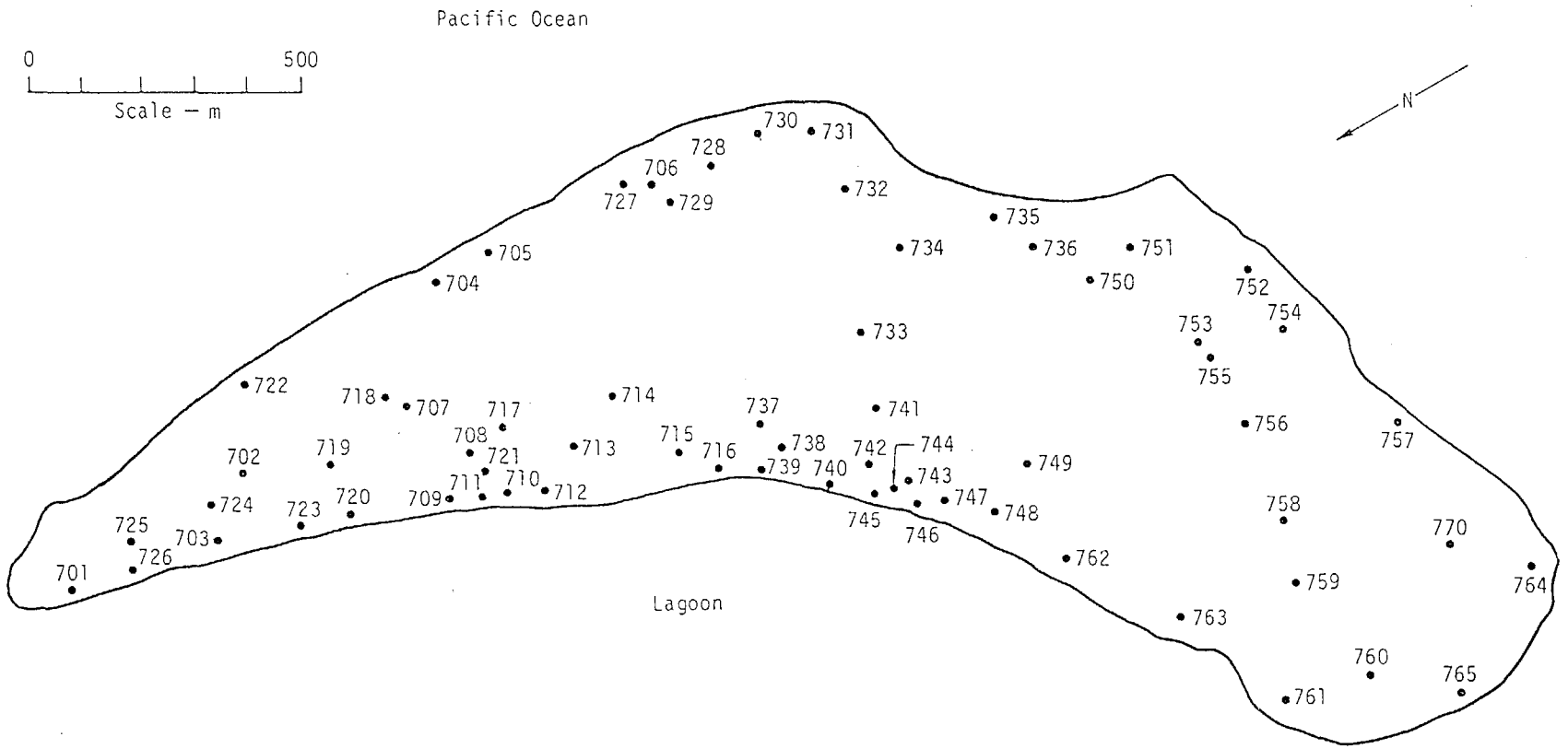

Fig. 2. Sampling sites of the Bikini (a) and Eneu (b) surface-soil sampling program.

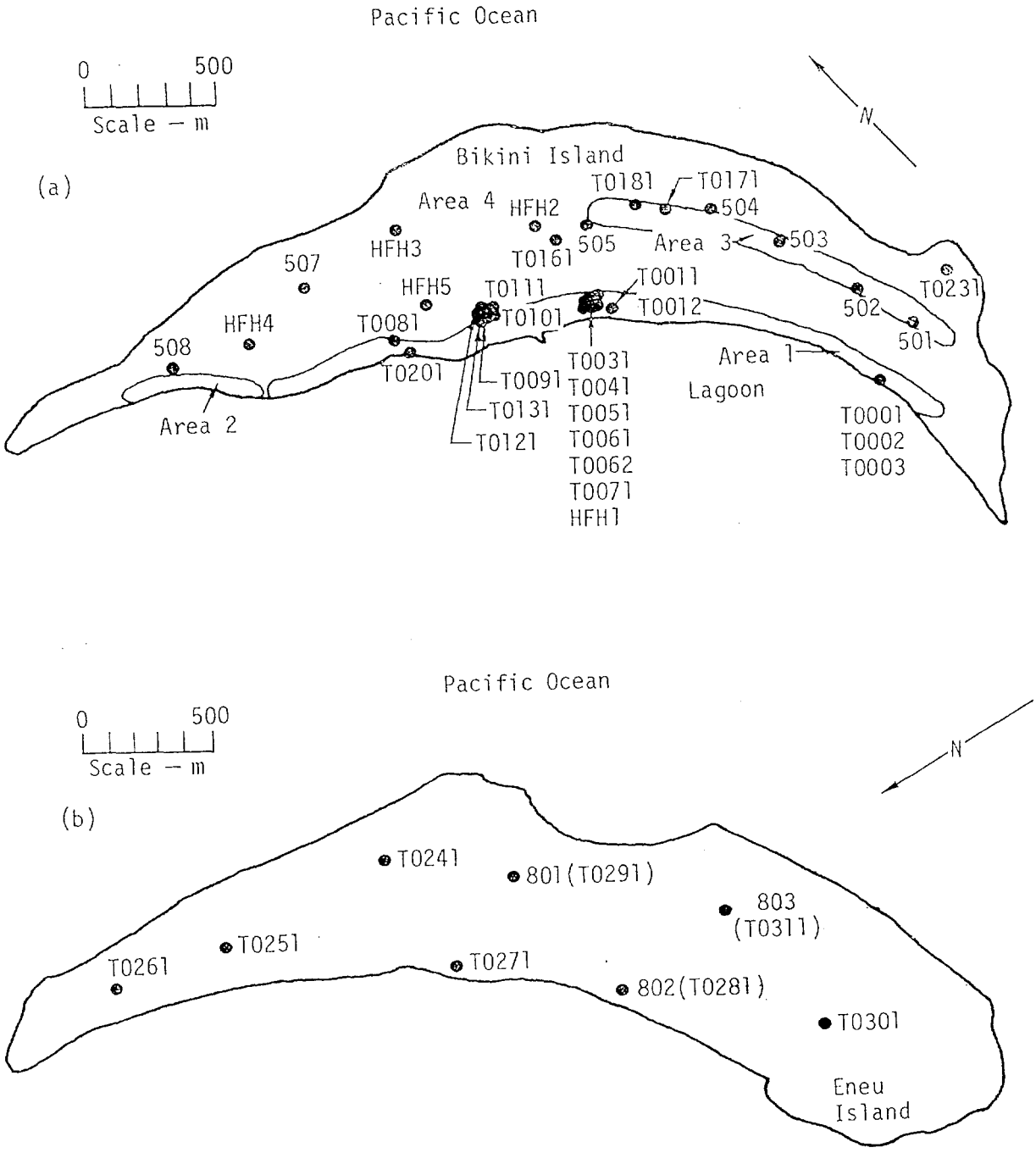

Fig. 3. Sampling sites of the Bikini (a) and Eneu (b) soil profile and vegetation samples.

concentrations in plant samples and from the average measured concentration in the associated 0- to 25-cm soil profile. We define the concentration factor, CF, as

$$CF = \frac{\text{pCi/g dry plant}}{\text{pCi/g dry soil}} .$$

To reduce the variability in average soil concentrations (used to calculate the concentration factor), we used a 0- to 25-cm soil profile that encompasses a large fraction of the effective absorptive root zone rather than the deeper 0- to 55-cm profile that encompasses the entire root zone. Concentration factors calculated on the basis of the average soil concentration in the upper 25 cm of the profile are somewhat greater but do not differ substantially from those based on the deeper profiles (Tables 1 and 2). All concentration factors reported here are therefore those derived from average 0- to 25-cm soil concentrations.

The average 0- to 25-cm soil concentration is calculated as the weighted geometric mean for the separate concentrations, measured at various increments throughout the profile. Concentration values less than the minimum detection limit are set equal to the detection limit, following the U.S. Environmental Protection Agency technique.

Whenever the number of samples is large enough, soil concentrations are plotted against concentrations in plants from the same sampling site; the results are analyzed with linear regression methods. These linear regression results are "statistically significant" at the 0.1-level of a standard F test. For each combination of nuclide, plant organ, and species considered, statistically significant regression equations are compared to the median of the calculated concentration factors and a single representative concentration factor is assigned.

Predictions of radionuclide levels in foodstuffs can be made from concentration factors if measured soil concentrations are available; however, concentration ratios are also needed if the only available data are from mature leaf samples. The concentration ratio is defined as the ratio of the concentration in fruit to the concentration in leaves of the same species; or, as the concentration in leaves of one species to the concentration in leaves of another species. We calculted preliminary ratios for all available species from the 1975 Bikini survey. However, because of the small number of samples involved, a statistical analysis of these results was not possible.

Table 1. Average radionuclide concentration for 0- to 25-cm and deeper soil profiles.

Location[a]	Average Soil Concentration, pCi/g dry weight			
	^{90}Sr	^{137}Cs	^{239}Pu	^{240}Pu
T0001 (0-25)[b]	81	45	4.3	4.7
(0-40)	70	27	1.6	1.8
T0051 (0-25)	202	150	9.2	10
(0-45)	208	165	9.2	10
T0061 (0-25)	42	28	1.4	1.6
(0-55)	150	85	5.1	5.7
T0062 (0-25)	67	31	2.3	2.5
(0-45)	80	37	1.3	1.5
T0081 (0-25)	126	43	2.2	2.5
(0-45)	70	15	0.53	0.64
T0121 (0-25)	89	50	2.0	2.2
(0-55)	34	25	0.52	0.60
T0161 (0-25)	27	34	1.5	1.7
(0-55)	30	25	1.1	1.2
T0181 (0-25)	94	13	2.4	2.8
(0-55)	62	5	0.56	0.70
T0191 (0-25)	36	23	0.99	1.2
(0-55)	28	18	0.87	1.0
T0241 (0-25)	3.7	3.3	0.42	0.46
(0-45)	4.7	2.8	0.49	0.47
T0251 (0-25)	7.3	7.9	0.24	0.27
(0-45)	9.8	5.7	0.42	0.45
T0261 (0-25)	7.8	4.6	0.41	0.47
(0-45)	6.8	1.8	0.23	0.38
T0271 (0-25)	1.0	0.88	0.12	0.14
(0-45)	0.62	0.40	---c	---
T0301 (0-25)	16	10	1.1	1.2
(0045)	20	12	1.6	1.5

[a] Sample locations are shown in Fig. 2.

[b] Depth of soil profile in centimeters.

[c] Not detected.

Table 2. Soil-mature leaf concentration factors calculated for 0- to 25-cm and deeper soil profiles.

Location[a]	Concentration Factor, (pCi/g dry leaf)/(pCi/g dry soil)			
	^{90}Sr	^{137}Cs	^{239}Pu	^{240}Pu
T0001 (0-25)	1.0	17	0.01	0.01
(0-40)	1.2	29	0.038	0.01
T0051 (0-25)	0.94	0.30	0.050	0.0053
(0-40)	0.92	0.27	0.050	0.0052
T0061 (0-25)	5.3	2.5	0.043	0.045
(0-55)	0.15	0.82	0.012	0.013
T0062 (0-25)	2.8	2.2	0.049	0.045
(0-55)	3.3	1.9	0.028	0.013
T0081 (0-25)	1.4	0.79	0.019	0.0494
(0-45)	2.4	2.3	0.078	0.029
T0121 (0-25)	1.2	2.9	0.030	0.021
(0-55)	2.5	5.9	0.066	0.084
T0161 (0-25)	0.22	13	0.018	0.014
(0-55)	0.19	18	0.024	0.054
T0181 (0-25)	0.11	35	0.012	0.018
(0-55)	0.17	9.3	0.051	0.0245
T0191 (0-25)	0.56	17	0.025	0.013
(litter) (0-55)	0.72	23	0.029	0.051
T0251 (0-25)	0.30	1.1	---[b]	---
(0-45)	0.19	1.3	---	---
T0261 (0-25)	0.16	3.9	0.010	0.013
(0-45)	0.12	5.4	0.0059	0.069
T0261 (0-25)	0.099	2.6	---	---
(0-45)	0.20	6.6	---	---
T0271 (0-25)	---	16	---	---
(0-45)	---	36	---	---
T0301 (0-25)	0.11	2.3	---	---
(0-45)	0.085	2.0	---	---

[a] Sample locations are shown in Fig. 2.

[b] No data.

Results and Discussion

SURFACE SOIL SURVEY

Although more samples are available from the 1975 Bikini survey than from any previous survey (Table 3), there is little consistency in the geographical distribution of ^{60}Co, ^{90}Sr, ^{137}Cs, $^{239,240}Pu$, and ^{241}Am on Bikini and Eneu Islands (see Appendix C). The maps and overlays in Appendix C present the activities of these radionuclides in picocuries per gram of dry soil over the sites from which the samples were collected. A list of concentrations of all detectable nuclides for each sampling site is given in Appendix D (microfiche included in pocket on inside back cover). A dry-soil density of 1.5 g/cm^3 may be used to convert the integrated profile data into activity per unit area. However, some caution must be exercised in such calculations because a significant fraction of the total activity may be located below the sampling depth.

Table 4 presents the means of the surface-soil concentrations of the dominant nuclides for Eneu Island and for the four areas of interest on Bikini Island. The values for Eneu are consistently ten times lower than concentrations for any part of Bikini Island. As expected, on Bikini Island, Area 1 shows the lowest soil concentration, since it is an exposed beach area that has been cleared for housing. Data from Bikini[8] and Enewetak[12] have revealed that soil activity is directly related to the amount of vegetation present in the area surrounding the sampling site. One possible reason for this is that a heavy vegetative cover can protect the underlying soil, minimizing the effects of weathering processes (e.g., wind and rain erosion) that transport surface activity through the soil column to the water lens. Follow-up field work at Enewetak Atoll has also shown that, in heavily vegetated areas, litter increases the soil retention of radionuclides.[13]

Although soil concentrations of radionuclides in Area 2 appear to be higher for ^{90}Sr and $^{239,240}Pu$ than in any other area on Bikini, statistical analysis of the ^{90}Sr concentrations for each of the four areas on Bikini, using the Mann-Whitney nonparametric test, shows no significant difference between the concentrations in the various areas. However, a more extensive analysis is needed to better define the real differences in concentrations in the various areas.

Table 3. Number of vegetation and soil samples in various Bikini surveys.

Species, Organ	Number of Samples					
	^{90}Sr		^{137}Cs		$^{239,240}Pu$	
	64-74[a] Survey	1975[b] Survey	64-74 Survey	1975 Survey	64-74 Survey	1975 Survey
Pandanus, leaves[c]		6 (6)[d]		6 (6)		5 (5)
fruit	6	1 (1)	4	1 (1)		1 (1)
Papaya, leaves		8 (4)		8 (4)		8 (4)
fruit		4 (4)		4 (4)		4 (4)
Breadfruit, leaves		2 (2)		2 (2)		2 (2)
fruit	0	1 (1)	0	1 (1)		1 (1)
Banana, leaves		3 (3)		3 (3)		3 (3)
Coconut, leaves		22 (8)		22 (8)		22 (8)
fruit	5	6 (6)	48	6 (6)		6 (6)
Scaevola, leaves		8 (2)		8 (2)		8 (2)
fruiting body		1 (1)		1 (1)		1 (1)
Messerschmidia, leaves		6 (3)		6 (3)		6 (3)
Soil Profiles	5	42	22	42		42
Soil, top 15 cm	21	196	176	196		196

[a] Data from 1974 Bikini draft (unpublished).

[b] Data from this report.

[c] Leaves include both mature and young specimens.

[d] Number of samples that have directly associated soil profiles.

Table 4. Median surface soil concentrations (0 to 15 cm).

Nuclide	Soil Concentration, pCi/g dry weight					
	Area 1	Area 2	Area 3	Area 4	Bikini Island[a]	Eneu Island
^{60}Co	0.59 (51)[b]	0.98 (6)	0.94 (32)	0.92 (87)	0.86 (176)	0.067 (66)
^{90}Sr	41 (35)	126 (5)	69 (18)	68 (70)	76 (128)	4.1 (73)
^{137}Cs	34 (51)	43 (6)	48 (33)	48 (88)	43 (178)	2.9 (68)
$^{239,240}Pu$	2.3 (70)	4.5 (10)	2.1 (34)	3.0 (140)	3.0 (254)	0.25 (146)
^{241}Am	1.8 (51)	3.7 (6)	2.7 (31)	2.7 (87)	2.4 (175)	0.22 (68)

[a] Arithmetic average of soil concentration in Areas 1-4 on Bikini Island.

[b] Number of samples taken.

SOIL PROFILES

Soil profiles from different parts of Bikini and Eneu Islands show a wide range of activity distributions with depth. (A listing of the concentrations measured for each profile is given in Appendix A and the data are presented graphically in Appendix B.) As noted by Held,[14] different plant-soil environments exhibit different vertical patterns of nuclide migration. The nearly complete disruption of the upper soil layers at Bikini Atoll by clearing, construction, and testing over the past 30 years as well as by agricultural practices initiated more recently has created a variety of plant-soil environments. Thus, the inhomogenity of the soil on these islands is not surprising. However, because of this inhomogenity, generalizations are not very meaningful, and these islands cannot be characterized by "average vertical profiles" with which to formulate cleanup criteria and to estimate dose.

The four basic types of profiles delineated at Enewetak Atoll[12] are all present on Bikini Island (see Fig. 4). Although we could not identify any particular profile type for extensive areas on Bikini Island, specific locations can be assigned "typical" profiles for predictive purposes. For example, on Bikini Island a group of samples taken in close proximity to one another (T0091, T0101, T0111, T0121, and T0131) show generally decreasing activity levels with depth despite

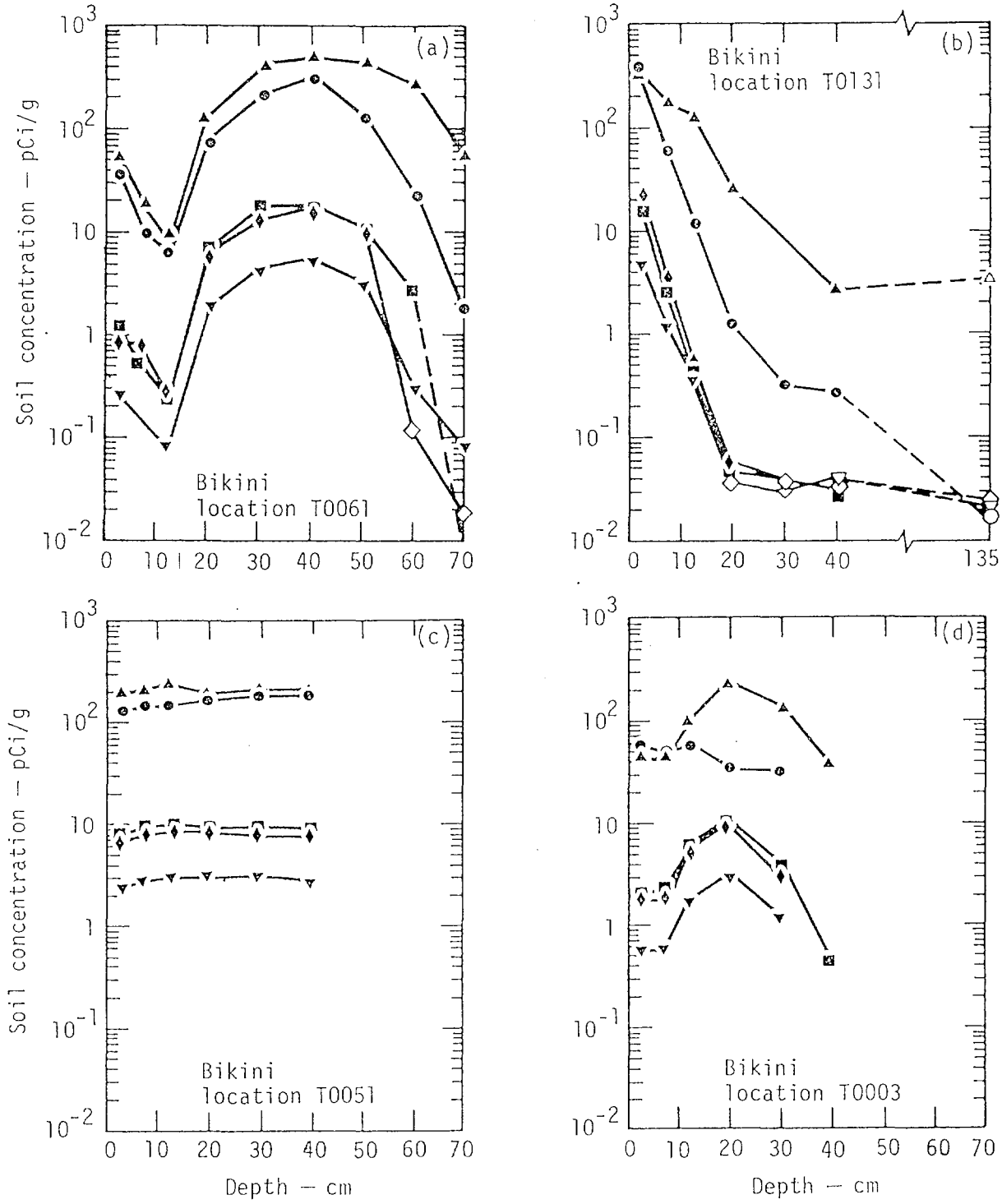

Fig. 4. Basic profile types from Gudiksen[11]: (a) erratic, (b) sharp drop-off, (c) uniform throughout, and (d) increasing then decreasing.

some variability in pattern in the upper parts of the profiles (see Figs. 5-9; Appendices A and B). Other locations, limited in area, can be assigned different "typical" profiles.

In general, profiles from Bikini Island show decreasing activity levels with depth. In contrast, those from Eneu Island exhibit a pattern of uniform or slowly decreasing activity levels from surface to total-sampled depth. The variations seen in the profiles on Bikini may be the result of the location of organic layers in the profile. Because organic matter tends to concentrate radioactivity,[15] nonuniform patterns of radionuclide concentration may result from organic layers that have been buried recently by construction and rehabilitation activities.

Although it is difficult to generalize about patterns of activity distribution, the relative concentrations of the dominant nuclides show a consistent trend: ^{90}Sr and ^{137}Cs >

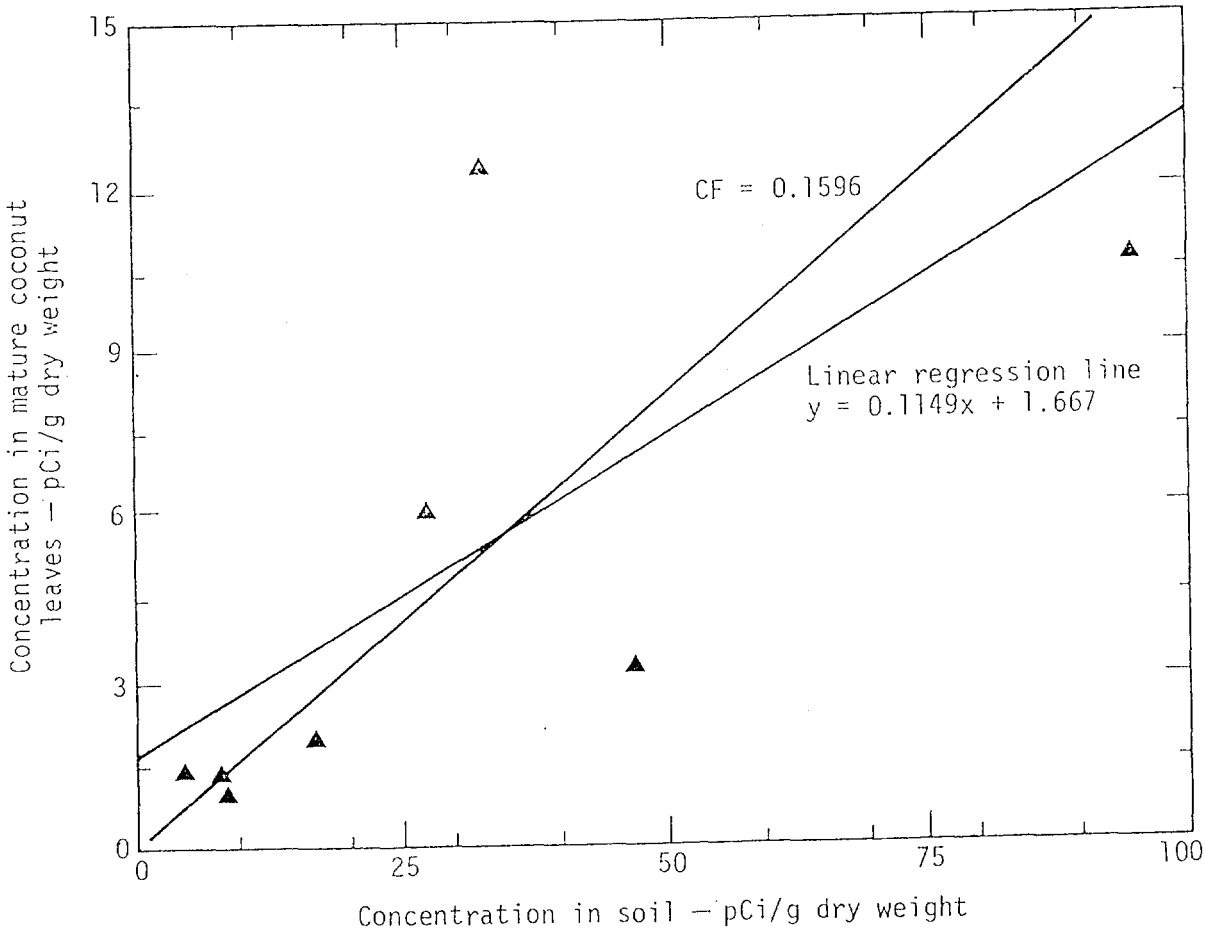

Fig. 5. Correlation of the ^{90}Sr concentration in mature coconut leaves with the concentration of ^{90}Sr in the soil at the same site.

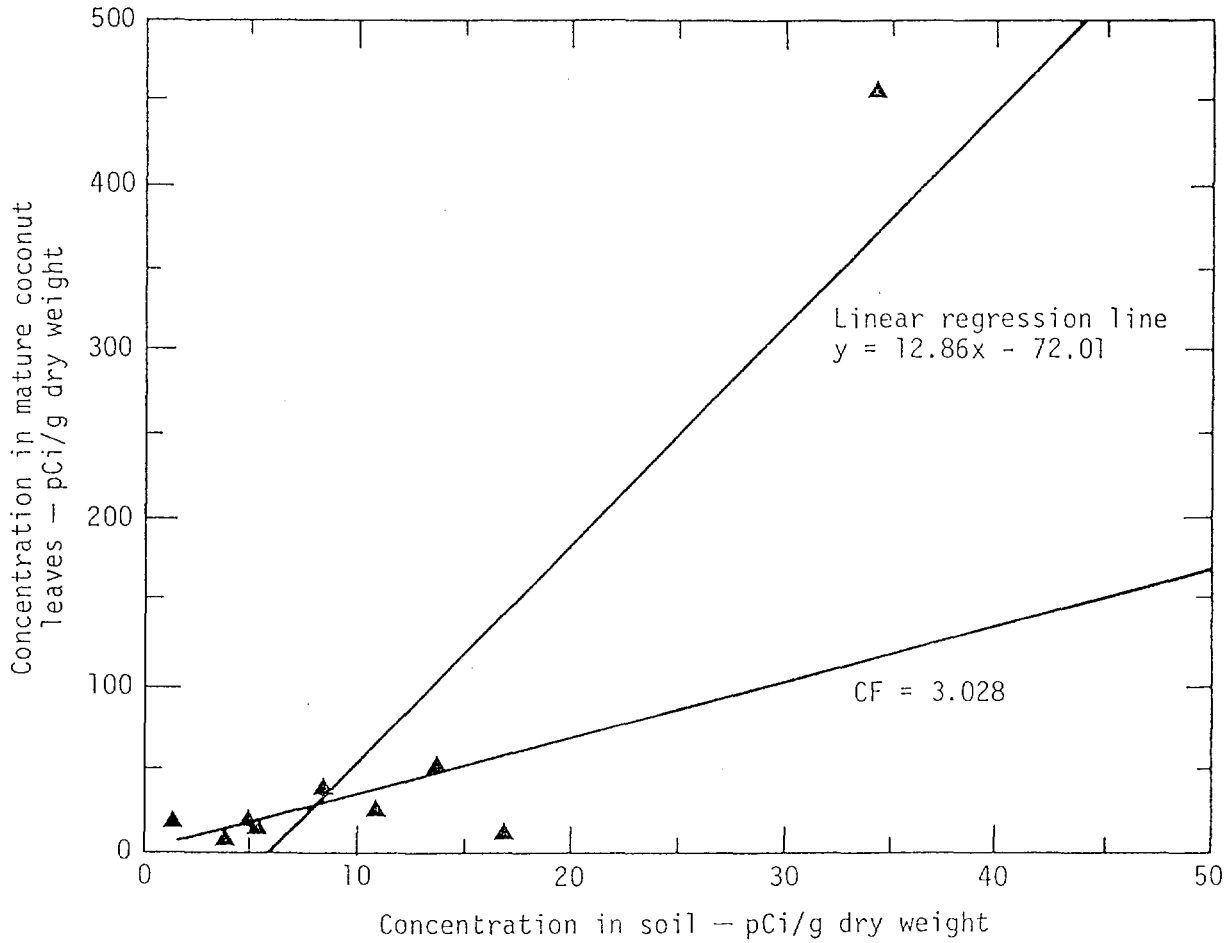

Fig. 6. Correlation of the ^{137}Cs concentration in mature coconut leaves with the concentration of ^{137}Cs in the soil at the same site.

$^{239,240}Pu$ and ^{241}Am > ^{60}Co. The concentration of ^{90}Sr on Bikini Island is usually twice that of ^{137}Cs, ten times that of $^{239,240}Pu$ and ^{241}Am, and thirty to forty times that of ^{60}Co (Table 4). As mentioned previously, soil concentrations on Eneu are about ten times lower than those on Bikini Island for all the radionuclides considered.

PREDICTION OF PLANT UPTAKE

Average concentrations in the 0- to 25-cm portions of the soil profiles are combined with measured concentrations in plants to predict the uptake of various radionuclides from the soil. In general, these plant-soil relationships from the 1975 Bikini survey confirm the results of previous surveys; however, the relationships are often statistically insignificant.

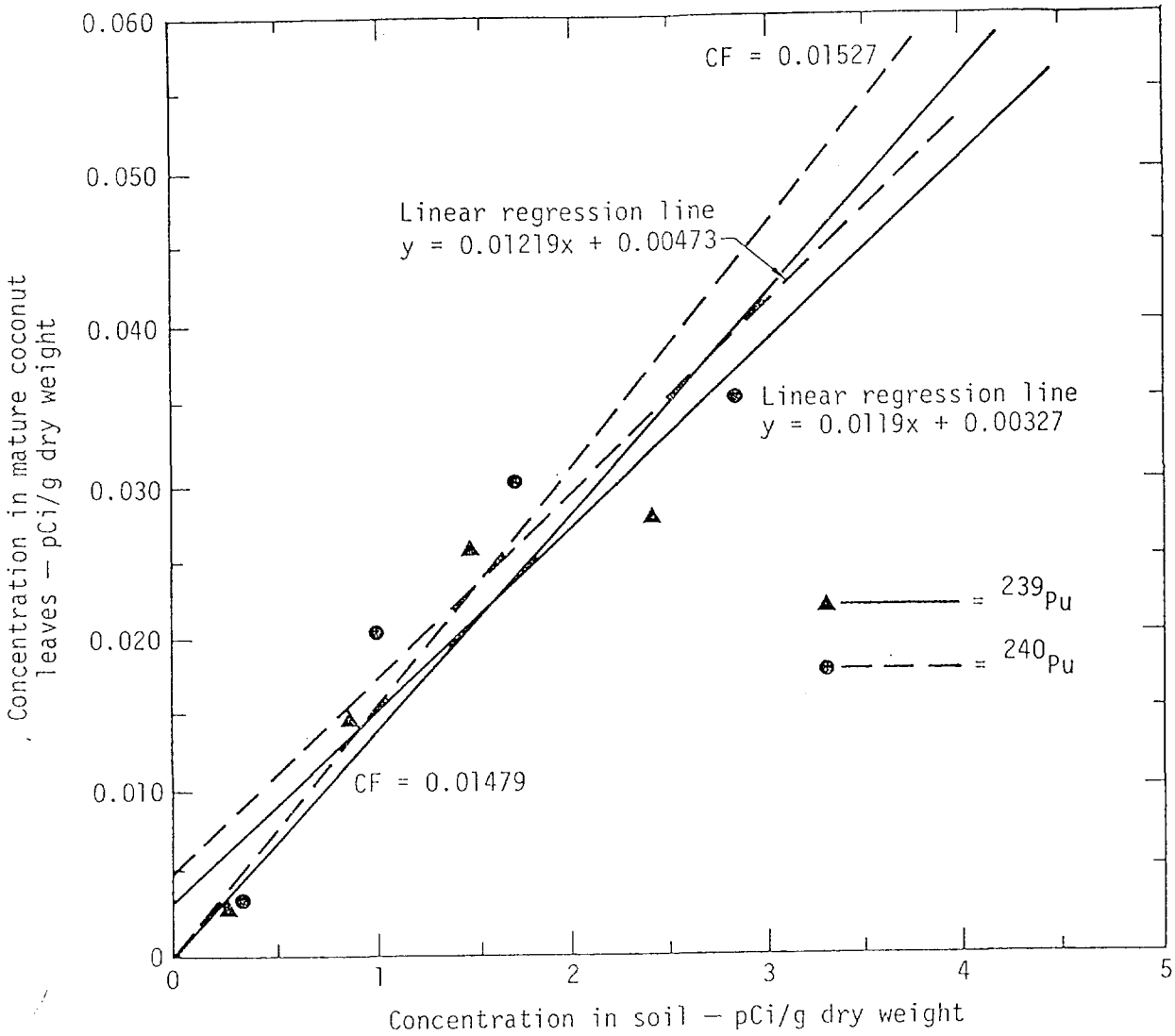

Fig. 7. Correlation of the $^{239,240}Pu$ concentration in mature coconut leaves with the concentration of $^{239,240}Pu$ in the soil at the same site.

In surveys where the number of samples considered for any one case is small, relationships that appear to be statistically insignificant are often extremely significant, since sampling errors may dominate the explanatory variables. Although statistical analysis of a larger number of samples is necessary to verify the results, we recommend the use of the general plant-soil relationships developed in this study for subsequent dose assessments.

Concentration Factors

Soil profiles with uniform patterns of nuclide migration are seldom found at Bikini Atoll as a

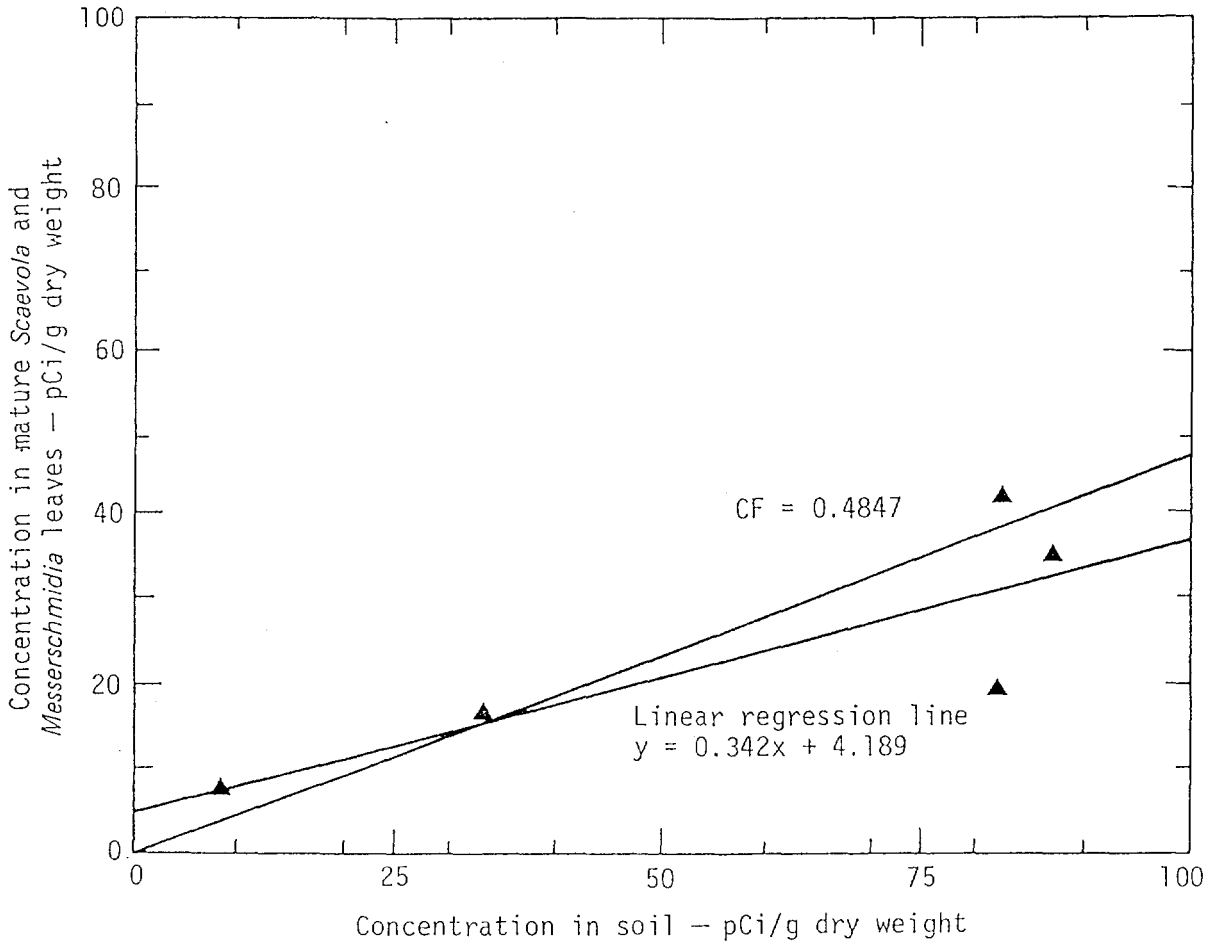

Fig. 8. Correlation of the ^{90}Sr concentration in mature *Scaevola* and *Messerschmidia* leaves with the concentration of ^{90}Sr in the soil at the same site.

result of the complete disruption of the upper soil layers by clearing, construction, and testing over the past 30 years as well as by more recent agricultural practices. To determine the soil concentrations of nuclides that are actually available to the root system of a specific plant, we sampled soil profiles in direct contact with the root system. The two replicate samples of soil profiles show minimal variation, regardless of the side of the plant from which they were taken (Table 5). In contrast, profiles in the general area but not in direct contact with the root system of the plant sample are highly variable (Table 6).

Tables 7 and 8 present the range and median values of concentration factors calculated for vegetation and soil sampled from the same location. Table 9 compares the information from these tables with the same information

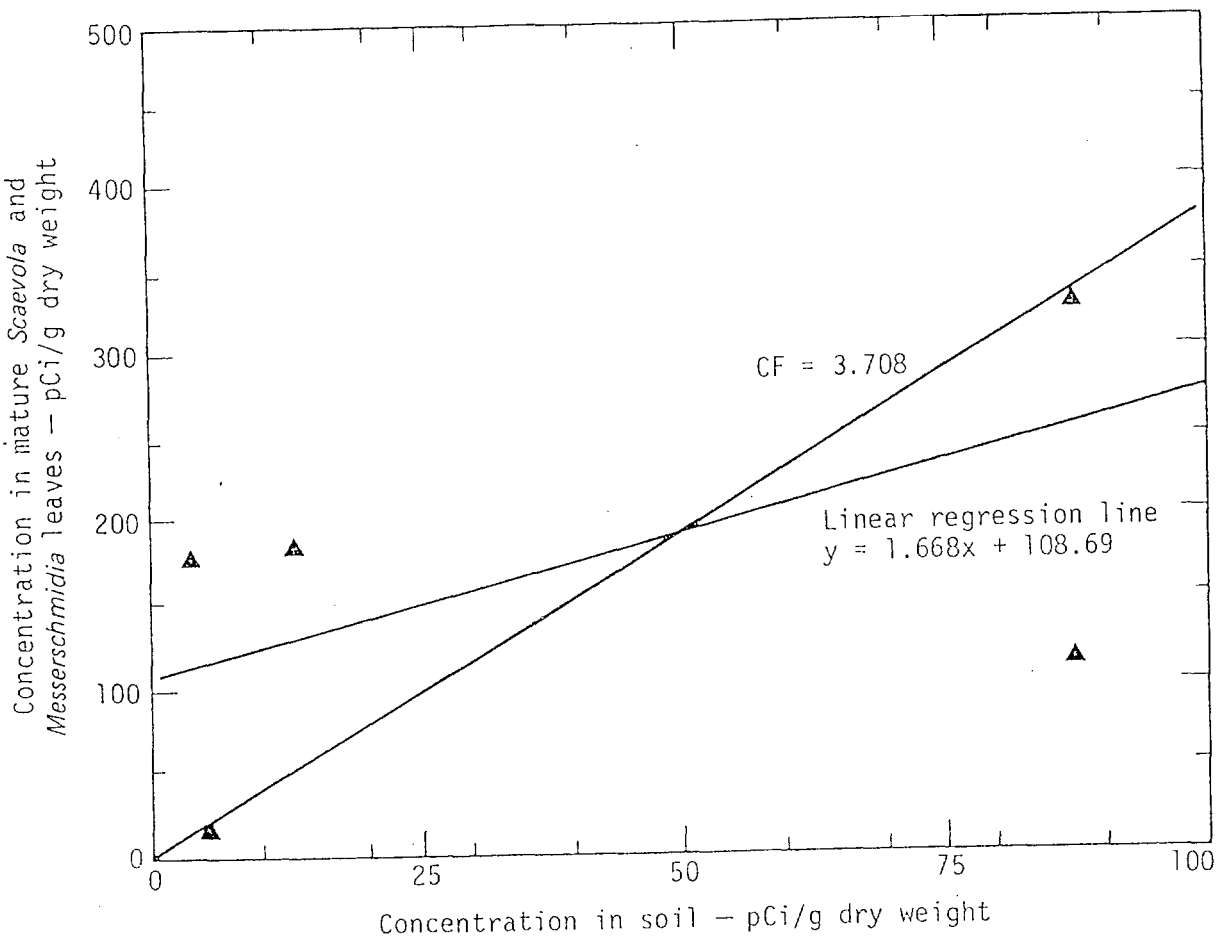

Fig. 9. Correlation of the ^{137}Cs concentration in mature *Scaevola* and *Messerschmidia* leaves with the concentration of ^{137}Cs in the soil at the same site.

for concentration factors calculated for mature *Scaevola* and coconut leaf samples for which no soil samples from the same location are available. We selected mature *Scaevola* and coconut leaves for this comparison because they provide the largest number of samples in both the associated and unassociated categories. A comparison of the ranges in Table 9 shows the importance of using associated plant-soil data (data from the same sampling site). Concentration factors calculated from unassociated plant and soil factors show a variation of three orders of magnitude in the case of ^{137}Cs uptake by mature *Scaevola* leaves while concentration factors calculated from associated data vary by one order of magnitude or less. These results agree with the wide range of concentration factors calculated in previous surveys from unassociated plant and soil samples.[1,4]

Table 5. Radionuclide concentrations in replicate 0- to 25-cm soil profiles.

Location[a]	Average Soil Concentration, pCi/g dry weight			
	^{90}Sr	^{137}Cs	^{239}Pu	^{240}Pu
Group 1				
T0001	81	45	4.3	4.7
T0002	92	29	4.6	5.1
T0003	101	44	5.0	5.5
Group 2				
T0061	42	28	1.4	1.6
T0062	68	31	2.6	2.5

[a]Sampling sites are shown in Fig. 2.

Table 6. Radionuclide concentrations in 0- to 25-cm soil profiles taken from the same general area.

Location[a]	Average Soil Concentration, pCi/g dry weight			
	^{90}Sr	^{137}Cs	^{239}Pu	^{240}Pu
Group 1				
T0091	81	55	2.5	2.8
T0101	32	35	0.27	0.29
T0111	81	87	3.3	3.7
T0121	89	50	2.0	2.2
T0131	86	13	0.53	0.64
Group 2				
T0031	6.8	8.6	0.18	0.20
T0041	35	26	0.58	0.69
T0051	202	150	9.2	10
T0061	42	28	1.2	1.6
T0071	127	86	4.6	5.1

[a] Sampling sites are shown in Fig. 2.

Table 7. Soil-to-plant uptake of ^{90}Sr and ^{137}Cs from plants and soils sampled at the same location.

	Concentration Factor, (pCi/g dry plant)/(pCi/g dry soil)							
	^{90}Sr				^{137}Cs			
Species, Organ	No. of Samples	Minimum	Maximum	Median	No. of Samples	Minimum	Maximum	Median
Scaevola, mature leaves	2	0.24	0.41	0.33	2	1.3	14	7.4
Messerschmidia, mature leaves	3	0.48	0.86	0.52	3	2.1	50	3.7
Pooled *Scaevola* & *Messerschmidia*, mature leaves	5	0.24	0.86	0.48	5	1.3	50	3.7
Coconut, mature leaves	7	0.099	0.38	0.16	8	1.1	16	3.0
Coconut, "fruit"	2	0.024	< 0.018	---	2	1.4	3.6	2.5
Coconut, meat	2	< 0.019	0.026	---	2	7.3	9.8	8.6
Coconut, milk[a]	2	< 0.0084	< 0.012	---	2	0.90	1.4	
Pandanus, mature leaves	5	0.71	2.4	0.91	5	2.9	25	15
Pandanus, green fruit	1	---[b]	---	0.53	1	---	---	0.054
Papaya, mature leaves	4	0.62	4.0	1.3	4	0.30	5.9	3.1
Papaya, fruit	4	0.12	0.85	0.43	4	1.9	18	8.2
Breadfruit, mature leaves	2	1.4	2.3	1.8	2	0.79	2.4	1.6
Breadfruit, mature fruit	1	---	---	0.76	1	---	---	7.0
Banana, mature leaves	2	0.48	1.1	0.73	2	0.33	0.54	0.42
Squash, whole plant	1	---	---	3.4	1	---	---	26
Squash, seeds	1	---	---	0.15	1	---	---	56

[a] Coconut milk was measured and reported in pCi/ml wet weight which, for calculation of the concentration factor, was assumed to equal pCi/g wet weight. Thus, the concentration factor for coconut milk is in (pCi/g wet weight)/(pCi/g dry soil).

[b] No data.

Table 8. Soil-to-plant uptake of $^{239,240}Pu$ from plants and soils sampled at the same location.

	Concentration Factor, (pCi/g dry plant)/(pCi/g dry soil)							
	^{239}Pu				^{240}Pu			
Species, Organ	No. of Samples	Minimum	Maximum	Median	No. of Samples	Minimum	Maximum	Median
Scaevola, mature leaves	1	---[a]	---	0.0047	1	---	---	0.0051
Messerschmidia, mature leaves	2	0.024	0.11	0.067	2	0.045	0.12	0.081
Pooled *Scaevola* & *Messerschmidia*, mature leaves	3	0.0047	0.11	0.024	3	0.0051	0.12	0.045
Coconut, mature leaves	4	0.010	0.022	0.015	4	0.0113	0.021	0.015
Pandanus, mature leaves	4	0.0044	0.030	0.016	4	0.0043	0.015	0.014
Papaya, mature leaves	4	0.0013	0.037	0.037	4	0.0053	0.041	0.026
Papaya, fruit	2	0.0013	0.0021	0.0017	2	0.0013	0.0023	0.0018
Breadfruit, mature leaves	2	0.0063	0.019	0.013	2	0.0213	0.062	0.042
Banana, mature leaves	2	0.0017	0.0054	0.0036	2	0.0018	0.0066	0.0042

[a] No data

Table 9. Soil-mature leaf concentration factors calculated from associated[a] and unassociated[b] data.

	Concentration Factor, (pCi/g dry plant)/(pCi/g dry soil)							
	Associated				Unassociated			
Nuclide, Species	No. of Samples	Minimum	Maximum	Median	No. of Samples	Minimum	Maximum	Median
^{90}Sr, *Scaevola*	2	0.24	0.41	0.33	4	0.048	4.3	1.8
^{90}Sr, coconut	7	0.099	0.38	0.16	15	0.041	0.74	0.29
^{137}Cs, *Scaevola*	2	1.3	14	7.5	4	0.073	39	7.7
^{137}Cs, coconut	8	1.1	16	3.0	15	0.53	18	2.6
^{239}Pu, coconut	4	0.011	0.022	0.015	12	0.0036	0.14	0.016
^{240}Pu, coconut	4	0.011	0.021	0.015	12	0.0021	0.15	0.016

[a] Plant and soil data sampled from the same site.

[b] Plant and soil data sampled from different sites in the same general area.

Because the range of concentration factors in only two combinations of nuclide, plant part, and species from the associated soil-plant data (pooled *Scaevola-Messerschmidia* leaves for ^{137}Cs and papaya leaves for ^{239}Pu) varied by more than a factor of 20 (Table 10), we use the median concentration factors derived from the associated data in our predictive model.

Several reasons explain the variation of concentration factors calculated from associated plant and soil data, including differences in the physiochemical properties of the radionuclides under consideration, in soil type and chemical characteristics, in soil management practices, in irrigation practices, and in the physiology, age, and prior history of the plants sampled. It is impossible

Table 10. Maximum-to-minimum ratios of associated soil-plant concentration factors.

Species, Organ	Maximum-to-Minimum Ratio			
	^{90}Sr	^{137}Cs	^{239}Pu	^{240}Pu
Scaevola, mature leaves	1.7	10	---[a]	---
Messerschmidia, mature leaves	1.8	23	4.9	2.6
Pooled *Scaevola* and *Messerschmidia*, mature leaves	3.6	39	23	2.0
Pandanus, mature leaves	3.3	8.4	6.9	3.6
Coconut, mature leaves	3.8	14	2.1	1.8
Coconut, "fruit"[b]	< 7.2	2.6	---	---
Papaya, mature leaves	6.5	20	30	7.9
Papaya, fruit	7.4	9.5	1.7	1.8
Banana, mature leaves	2.3	1.6	3.2	3.8
Breadfruit, mature leaves	1.7	3.0	3.0	2.9

[a] Not detected.

[b] "Fruit" includes both meat and milk.

to identify the specific cause of each variation but the variation can be reduced by carefully controlling sampling techniques and by increasing the number of samples.

Where fruit data are unavailable, concentration factors calculated from mature leaf data are used as the basis for predicting concentrations of radionuclides in food available to the returning Bikini population. Mature leaf concentration factors in conjunction with correlations between various species and between leaves and fruit of the same species enable us to predict concentrations in fruit from measured concentrations in leaves of indicator or edible plants.

We only report concentration factors for ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$. As predicted from previous studies, the most effectively transferred radionuclide in the terrestrial environment is ^{137}Cs, although ^{90}Sr is often present in larger quantities in the soil of the atoll. This is partly explained by the differential solubilities of ^{90}Sr and ^{137}Cs in soil. Strontium-90 appears to be tied up as insoluble carbonates in the atoll soil and is thus less available to the plant. Cesium-137 is more soluble in the nonclay atoll soil; thus ^{137}Cs is more easily leached through the soil. Although ^{137}Cs is leached through the soil at a faster rate than ^{90}Sr, ^{137}Cs is also readily absorbed and accumulated in organified soil horizons where there is a proliferation of plant roots and litter. This accumulation of ^{137}Cs in organified soil horizons renders it more available than ^{90}Sr for uptake in plants.

The concentration factors discussed in the subsequent paragraphs generally reflect this relationship between the uptake of ^{90}Sr and ^{137}Cs. For *Pandanus*, coconut, *Scaevola*, and *Messerschmidia* leaves and for the fruit of all species, low concentration factors are observed for ^{90}Sr as compared to ^{137}Cs. However, leaves of papaya, banana, and breadfruit show concentration factors for ^{90}Sr as high or higher than those for ^{137}Cs. Concentration factors for $^{239,240}Pu$ are generally 10 to 100 times lower than those for either ^{90}Sr or ^{137}Cs. Although they are often measured in soil, ^{60}Co, ^{241}Pu, and ^{241}Am are only occasionally detected in vegetation. For this reason, we did not calculate concentration factors for these three nuclides.

In the following sections, we discuss the specific concentration factors assigned to each species. Concentration factors are assigned solely on the basis of the median calculated concentration factors except for coconut and for pooled *Scaevola* and *Messerschmidia* leaves.

For these last two cases, we had enough samples to justify analysis by linear regression methods. Thus, the regression results are compared with the median concentration factor and a representative value is chosen for our models. The relationships between the relative uptake of different species are considered in a separate section on concentration ratios.

Coconut. Coconut is the most abundant species on Bikini and Eneu Islands and thus it was sampled more extensively than any other plant in the 1975 survey. Unfortunately, few coconut trees were bearing fruit so the bulk of these samples are leaves. Regression analysis comparing mature coconut leaves and soil sampled from the same location shows correlations that are significant at the 0.1 to 0.05 level for ^{90}Sr, at the 0.005 level for ^{137}Cs, and at the 0.1 level for $^{239,240}Pu$ (Figs. 5-7). Combining the results of this regression analysis with the median calculated concentration factors (Table 11), we obtain final concentration factors for mature coconut leaves of 0.16 for ^{90}Sr, 3.0 for ^{137}Cs, and 0.015 for $^{239,240}Pu$.

Concentrations in both coconut milk and coconut meat were analyzed for the two samples from Bikini. When compared on a wet/wet or a dry/dry basis, there are no definitive patterns in the radionuclide concentrations of meat and milk taken from the same location.* Because the 1972 Enewetak data show no consistent differences in the uptake of ^{90}Sr and ^{137}Cs by coconut milk and meat, the ^{90}Sr and ^{137}Cs concentrations in fresh coconut meat and fresh coconut milk are assumed to be equal. The concentration factors from the Bikini data (Table 11) are within the range of those from the Enewetak survey,[1] so until more conclusive data are available, we have assigned a conservative concentration factor of 0.024 for ^{90}Sr and 2.5 for ^{137}Cs to both coconut meat and milk.

Pandanus -- Although the number of samples of mature *Pandanus* leaves is insufficient for statistical analysis, the concentration factors calculated from associated leaf-soil data for Bikini are within the range of those from Enewetak.[1] The median concentration factors of 0.91 for ^{90}Sr and 15.2 for ^{137}Cs are assigned to mature *Pandanus* leaves. The concentration factor calculated for the one green *Pandanus* fruit available from the Bikini survey (0.50 for ^{90}Sr and 5.4 for ^{137}Cs) is comparable to values from previous surveys and therefore, we

*Following the example of the Enewetak survey,[1] results are given in wet weight for coconut milk and in dry weight for coconut meat; coconut milk is assumed to be 95% water and coconut meat is assumed to be 50% water.

Table 11. Comparison of soil-root and soil-leaf concentration factors.

	Concentration Factor, (pCi/g dry plant)/(pCi/g dry soil)					
	^{90}Sr		^{137}Cs		$^{239,240}Pu$	
Species	Roots	Leaves	Roots	Leaves	Roots	Leaves
Pandanus	0.88	1.0	23	17	0.44	0.015
	0.77	1.2	26.1	2.9	0.45	0.022
Messerschmidia	0.59	0.48	33	50	0.44	0.35
Coconut	0.16	0.11	3.4	2.3	0.085	---
	0.89	---[b]	16	0.88	0.11	---
	0.30	0.30	5.7	1.1	0.081	---
	0.89	---	5.0	---	0.38	---
Banana	0.42[a]	1.10	0.026	0.54	0.027	0.006

[a] Root and crown.

[b] Below minimum detection limit.

consider it to be a valid sample and have used it in our dose predictions.

Breadfruit — Breadfruit were not available on Enewetak Atoll. Thus, data from the two samples collected during the 1975 Bikini survey provide the first directly measured concentration factors. As expected from the 1972 Bikini survey[16] and from the stable element analysis of potassium and calcium in the Enewetak survey,[1] uptake of ^{90}Sr and ^{137}Cs by breadfruit is high and comparable to uptake by *Pandanus*. Preliminary concentration factors of 1.8 for ^{90}Sr, 1.6 for ^{137}Cs, and 0.027 for $^{239,240}Pu$ are assigned to mature breadfruit leaves. The concentration factors for the one mature fruit sampled from this species are 0.76 for ^{90}Sr and 7.0 for ^{137}Cs.

Papaya — The ratio of maximum-to-minimum concentration factors calculated for mature papaya leaves is small; median concentration factors are 1.3 for ^{90}Sr, 3.1 for ^{137}Cs, and 0.0018 for $^{239,240}Pu$. Concentration factors of 0.43 for ^{90}Sr, 8.2 for ^{137}Cs, and 0.0018 for $^{239,240}Pu$ are calculated for the four papaya fruit available.

Banana — The only data from the 1975 Bikini survey on radionuclide concentrations in banana are for mature leaves. The two available samples suggest tentative concentration factors of 0.73 for ^{90}Sr, 0.42

for ^{137}Cs, and 0.0039 for $^{239,240}Pu$ in mature banana leaves. Unpublished data for banana fruit and soil samples from the same area collected in the 1972 Bikini survey yield concentration factors of < 0.058 for ^{90}Sr and <0.00028 for $^{239,240}Pu$.[17] Because no data are currently available for concentration factors for ^{137}Cs in bananas, we have assigned the conservative value of the ^{137}Cs concentration factor in mature banana leaves to banana fruit.

Messerschmidia and Scaevola — As discussed in the Enewetak survey,[1] the data from these two indicator plants show a significant correlation between leaves and soil on both an individual and a pooled basis. The number of samples from the Bikini survey does not warrant individual statistical analysis of these species. However, the pooled data show a correlation between leaves and soil that is significant at the 0.1 level for ^{90}Sr (Fig. 8) but is not significant for ^{137}Cs (Fig. 9). Cesium-137 does show a significant correlation between leaves and soil in the Enewetak results and probably would do so for Bikini if the number of samples were larger. Based on the median calculated concentration factors and on the results of the regression analysis, concentration factors of 0.49 for ^{90}Sr, 3.7 for ^{137}Cs, and 0.035 for $^{239,240}Pu$ were assigned to mature *Scaevola* and *Messerschmidia* leaves.

Squash — One sample of summer squash and its seeds was available from the 1975 survey. This is the first time measured radionuclide concentrations in garden vegetables from Bikini Atoll have been available. Squash uptake of ^{90}Sr and ^{137}Cs is greater than that of any other plant sampled. Other workers also have observed high concentrations of ^{137}Cs in garden vegetables as compared to concentrations in other edible and indicator plants. Lynch *et al.*[7] notes that in field studies, the ^{137}Cs concentration in lettuce leaves is an order of magnitude greater than the concentrations measured in other edible portions of food plants. In laboratory experiments to determine the uptake of ^{137}Cs by squash, Walker *et al.* report ^{137}Cs concentrations in squash that are higher than those measured in *Messerschmidia, Scaevola,* and *Pandanus* grown in the same Rongelap Atoll soil.[18] However, from Walker's experiments it appears that with the application of fertilizer, the concentrations in squash can be reduced to levels comparable to those found in other edible plants.

Concentration Ratios

Radionuclides that are taken up from the soil through roots are either retained in the roots or transported

to the aboveground plant organs. At Bikini, the concentrations of ^{90}Sr in the aboveground plant organs of a species are comparable to the concentrations retained in the roots of that species. However, concentrations of ^{137}Cs and $^{239,240}Pu$ are lower in the aboveground plant organs than in roots (Table 11). In addition, there are differences in uptake among the various aboveground plant organs. Within any one species, concentrations of ^{90}Sr and $^{239,240}Pu$ are generally smaller in edible plant parts (e.g., fruit) than in nonedible organs (e.g., leaves); the opposite is true for ^{137}Cs (Table 12).

Because leaves are more often available for sampling than are fruit, we developed fruit-leaf concentration ratios to allow prediction of radionuclide concentrations in fruit from those measured in leaves of the same species (Table 13). The small number of samples makes it impossible to statistically evaluate these ratios; we will do this as more data become available. We also calculated leaf-leaf and fruit-fruit concentration ratios between different species for

Table 12. Summary of median soil-plant concentration factors.

	Concentration Factor, (pCi/g dry plant)/(pCi/g dry soil)					
	^{90}Sr		^{137}Cs		$^{239,240}Pu$	
Species	Mature Leaves	Fruit	Mature Leaves	Fruit	Mature Leaves	Fruit
Pooled *Scaevola* & *Messerschmidia*	0.48	---[a]	3.7	---	0.035	---
Coconut	0.16	0.024	3.0	2.5	0.015	---
Panadanus	0.91	0.50	15.0	5.4	---	---
Papaya	1.00	0.43	3.1	8.2	0.016	0.002
Breadfruit	1.80	0.76	1.6	7.0	0.027	---
Banana	0.73	0.058[b]	0.42	---	0.004	0.0003[b]
Squash	3.40[c]	0.15[d]	26.0[c]	56.0[d]	---	---

[a] Not detected.

[b] 1974 unpublished plant and soil data from the same vicinity.[17]

[c] Whole plant.

[d] Seeds.

Table 13. Fruit-leaf concentration ratios.

Species	Nuclide	Concentration, pCi/g dry weight		Fruit/Leaf Concentration Ratio
		Fruit	Mature Leaves	
Pandanus	^{90}Sr	40[a]	8	0.50
	^{137}Cs	2.7	146	0.02
Breadfruit	^{90}Sr	61	190	0.33
	^{137}Cs	384	132	3.00
Coconut "fruit"	^{90}Sr	0.79	12	0.06[c]
		1.9	2.9	
	^{137}Cs	60	7.1	4.00[c]
		14	9.7	
		54	15	
Coconut meat/milk	^{90}Sr	0.41/0.18	1.7	0.33
	^{137}Cs	76/9.3	24	3.00
Papaya	^{90}Sr	18	264	0.20[c]
		22[a]	22	
		49	191	
		47	221	
	^{137}Cs	865[b]	189	5.00
		160[a]	156	
		281	45	
		303	69	
	$^{239,240}Pu$	0.014[b]	0.049	0.03
		0.0023	0.067	

[a] Green fruit.

[b] Fallen fruit.

[c] Based on all available data.

prediction of concentrations in fruit of one species from those in fruit or leaves of another species. These ratios show that distribution patterns for each nuclide are consistent within a particular species. However, we must remember that the importance of the contribution of each nuclide to the internal dose to man varies with different species.

The fruit-fruit and fruit-leaf concentration ratios are calculated from a comparison of the concentration factors of three plant groups (plants within each group were sampled from the same general location) and from comparisons of the median concentration ratios of all associated plant-soil samples (Table 14). Analysis of the concentration ratios for mature leaves and fruit suggests that some species concentrate a given nuclide to a much greater extent than do others (Tables 15-19). For ^{90}Sr in mature leaves, the concentration decreases in the order: breadfruit and papaya > *Pandanus* and banana > *Messerschmidia* and *Scaevola* > coconut (Tables 15 and 18). These results agree with those of Welander.[10]

The relative uptake of ^{137}Cs by the various species differs slightly from that of ^{90}Sr. For ^{137}Cs in mature leaves, the concentration appears to decrease with *Pandanus* > *Scaevola* > *Messerschmidia*, coconut, and papaya > breadfruit > banana. A comparison of ^{137}Cs uptake by fruit yields the pattern: papaya > *Pandanus* and breadfruit > coconut (Tables 16 and 19). The data for the uptake of $^{239,240}Pu$ by mature leaves are much more limited than data for ^{90}Sr and ^{137}Cs, but preliminary results suggest: *Messerschmidia* > breadfruit > *Pandanus* and coconut > papaya > *Scaevola* and banana (see Table 17). Although no concentration ratios are calculated, the uptake of ^{90}Sr and ^{137}Cs by unfertilized summer squash exceeds that of all other edible plants sampled.

Summary and Conclusions

The radionuclide concentration in surface soil samples (0 to 15 cm) varies greatly throughout both Bikini and Eneu Islands. In addition to the inhomogeneity observed in surface soil concentrations, profile data indicate that radionuclide concentration as a function of soil depth is quite variable. (In some cases, the concentration at depths as great as 120 cm exceeds that in the top 2.5 cm.) As a result of the variability in surface soil concentrations with location and with depth, conclusions regarding dose reduction via soil removal must be exercised with great care. It is nearly impossible to generalize about remedial measures

Table 14. Associated soil-plant concentration factors for plant species sampled from the same location.

Species, Organ	Concentration Factor, (pCi/g dry plant)/(pCi/g dry soil) ^{90}Sr	^{137}Cs	$^{239,240}Pu$
Group 1[a]			
Papaya, mature leaves	1.6	3.9	0.012
Papaya, mature leaves	0.62	5.9	0.037
Papaya, mature leaves	0.94	0.30	0.0051
Papaya, mature leaves	4.0	2.9	0.027
Banana, mature leaves	0.48	0.33	0.0017
Banana, mature leaves	1.1	0.41	0.0060
Group 2[b]			
Breadfruit, mature leaves	2.3	2.4	0.063
Pandanus, mature leaves	1.2	2.9	0.022
Messerschmidia, mature leaves	0.48	87	0.035
Messerschmidia, mature leaves	0.52	3.7	---[d]
Scaevola, mature leaves	0.24	1.3	0.0049
Scaevola, mature leaves	0.41	14	---
Breadfruit, fruit	0.76	7.0	---
Pandanus, green fruit	0.53	5.4	---
Scaevola, fruit	0.14	1.4	0.00096
Group 3[c]			
Scaevola, mature leaves	4.3	39	0.024
Coconut, mature leaves	0.67	14	0.026
Coconut, mature leaves	0.27	7.3	0.020

[a] Group 1 includes samples T0010, T0030, T0040, T0050, T0060, T0070.

[b] Group 2 includes samples T0090, T0100, T0110, T0120, and T0130.

[c] Group 3 includes samples T0150 and T0160.

[d] Not detected.

Table 15. Strontium-90 leaf-leaf concentration ratios.

Species	Leaf-Leaf Concentration Ratio						
	Bread-fruit	Papaya	*Pandanus*	Banana	*Messer-schmidia*	*Scaevola*	Coconut
Breadfruit	1.0	1.5	2.0	2.5	3.5	6.0	12
Papaya	0.66	1.0	1.3	1.7	2.5	4.0	8.0
Pandanus	0.50	0.77	1.0	1.3	1.8	3.0	6.0
Banana	0.40	0.59	0.77	1.0	1.4	2.2	4.4
Messerschmidia	0.29	0.40	0.56	0.71	1.0	1.6	3.2
Scaevola	0.17	0.25	0.33	0.45	0.63	1.0	2.0
Coconut	0.08	0.12	0.17	0.23	0.31	0.50	1.0

Table 16. Cesium-137 leaf-leaf concentration ratios.

Species	Leaf-Leaf Concentration Ratio						
	Panadanus	*Scaevola*	*Messer-schmidia*	Coconut	Papaya	Bread-fruit	Banana
Pandanus	1.0	2.0	4.0	5.0	5.0	10.0	35
Scaevola	0.50	1.0	2.0	2.5	2.5	5.0	18
Messerschmidia	0.25	0.50	1.0	1.3	1.3	2.4	8.8
Coconut	0.20	0.40	0.80	1.0	1.0	2.0	7.0
Papaya	0.20	0.40	0.80	1.0	1.0	2.0	7.5
Breadfruit	0.10	0.20	0.40	0.50	0.50	1.0	3.8
Banana	0.03	0.06	0.12	0.14	0.13	0.26	1.0

entailing soil removal without first detailing the area and pathways that will be involved.

For example, the soil profile data (Appendices A and B) for Eneu and for some areas on Bikini indicate that removal of the top 10 cm of soil should do very little to reduce gamma exposure unless the removed soil is replaced with clean soil, thus shielding the deeper contaminated soil. There would also be very little impact upon uptake by plants because the soil concentration is essentially identical through the root zone up to depths of 40 cm.

However, there are other areas on Bikini Island, (Appendices A and B, locations 501, 502, 503, and 504,

Table 17. Plutonium-239,240 leaf-leaf concentration ratios.

Species	Leaf-Leaf Concentration Ratio			
	Messerschmidia	Breadfruit[a]	Papaya	*Scaevola*[b]
Messerschmidia	1.0	4.5	10	15
Breadfruit[a]	0.22	1.0	2.2	3.3
Papaya	0.10	0.45	1.0	1.5
Scaevola[b]	0.07	0.30	0.67	1.0

[a] Also includes *Pandanus* and coconut.

[b] Also includes banana.

Table 18. Strontium-90 fruit-fruit concentration ratios.

Species	Fruit-Fruit Concentration Ratios		
	Breadfruit	*Pandanus*[a]	Coconut
Breadfruit	1.0	1.5	3.0
Pandanus[a]	0.67	1.0	2.0
Coconut	0.33	0.50	1.0

[a] Also includes papaya.

Table 19. Cesium-137 fruit-fruit concentration ratios.

Species	Fruit-Fruit Concentration Ratio			
	Papaya	Breadfruit	*Pandanus*	Coconut
Papaya	1.0	1.3	1.6	3.2
Breadfruit	0.75	1.0	1.4	2.8
Pandanus	0.63	0.71	1.0	2.0
Coconut	0.30	0.36	0.50	1.0

respectively) where removal of the top 10 cm of soil would reduce soil concentrations by approximately five-fold. This of course would result in reduced external exposure and reduced uptake in plants grown in such areas.

Although considerable variation in soil radionuclide concentration is observed on both islands, the soil concentrations on Bikini Island are approximately ten times those on Eneu Island. In addition, the relative radionuclide soil concentrations are very consistent; concentrations of ^{90}Sr and ^{137}Cs are ten to twenty times greater than those of $^{239,240}Pu$ and ^{241}Am which, in turn, are two to three times greater than ^{60}Co concentrations. Therefore, generalizations can safely be made from the soil data to the effect that inhabitants on Bikini Island will be exposed to higher doses than those on Eneu Island. Also, on both islands, ^{90}Sr and ^{137}Cs are the radionuclides of primary importance.

In the past, concentrations in terrestrial foodstuffs at Bikini Atoll have been predicted from soil concentrations measured in the field and from concentration factors taken from the literature. This approach was adopted because vegetation sampling programs were limited in the early surveys. However, the terrestrial sampling program of the 1975 Bikini survey included sufficient vegetation samples to allow preliminary prediction of concentrations in nearly all components of the postulated Bikini diet. These predicted concentrations are based on soil-plant concentration factors and on fruit-leaf, leaf-leaf, or fruit-fruit concentration ratios calculated from the 1975 field data. The predicted concentrations compare favorably with the available measured concentrations. A more extensive survey of Bikini Atoll with larger sample sizes is needed to statistically verify these preliminary results. In the meantime, potential future concentrations in foodstuffs from Bikini can be predicted from our concentration factors if measured soil concentrations are available and from our concentration ratios if only vegetation samples are available. Estimates of the dose commitment expected from various projected lifestyles from our predicted concentrations are reported in Part 5 of this report series.[9]

The predominant nuclides in the terrestrial foodchain are ^{90}Sr and ^{137}Cs, followed by $^{239,240}Pu$, and will constitute the major internal dose to man from this pathway. In general, within a given species, ^{137}Cs uptake by fruit and leaves is one order of magnitude greater than ^{90}Sr uptake which, in turn, exceeds $^{239,240}Pu$ uptake by one to two orders of magnitude. Uptake by mature leaves of papaya, banana, and breadfruit varies

slightly from this general pattern; in these cases, the measured uptake of ^{90}Sr is equal to that of ^{137}Cs. However, more samples are needed to verify the pervasiveness of these exceptions to the overall patterns observed. The distribution of ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$ in fruit and leaves follows similar patterns in the various species studied. In a given species, ^{90}Sr and $^{239,240}Pu$ uptake by mature leaves is two to ten times greater than that by fruit. The ^{137}Cs uptake measured in this study shows a different trend; uptake by fruit exceeds uptake by mature leaves by a factor of two to five.

A comparison of the uptake of ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$ shows that, in general, the relative order of uptake is: squash (high; breadfruit, *Pandanus*, and papaya (intermediate); and banana and coconut (low). Slight variations occur, depending on the radionuclide under consideration. A more quantitative ordering can be made after greater numbers of all tissues of plants are sampled in future surveys.

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Appendix A. Soil Profiles of Bikini and Eneu Islands

The following tables present the concentration of eight selected radionuclides (^{60}Co, ^{90}Sr, ^{137}Cs, ^{155}Eu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{241}Am) with depth in the soil profile. Sample locations on the islands are given in Figs. 2 and 3. These data are also presented graphically in Appendix B.

PROFILE BIKINI 501

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	4.351E+00	2.370E+02	2.260E+02	5.744E+00	1.311E+01	1.449E+01	2.607E+02	1.373E+01	01048131
005-010	5.869E+00	3.271E+02	1.365E+02	7.946E+00	1.698E+01	1.866E+01	3.387E+02	2.053E+01	01048234
010-020	3.853E+00	2.942E+02	8.473E+01	4.734E+00	1.112E+01	1.251E+01	2.330E+02	1.253E+01	01048371
020-030	6.261E-02	2.046E+02	3.219E+01	<9.144E-02	6.748E-01	7.455E-01	1.312E+01	<1.539E-01	01048472
030-040	9.230E-02	8.815E+01	1.305E+01	<4.716E-02	4.586E-02	5.455E-02	-	<9.032E-02	01048573

PROFILE BIKINI 502

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	4.658E+00	2.871E+02	2.946E+02	7.270E+00	-	-	-	1.780E+01	01054531
005-010	5.477E+00	4.493E+02	3.130E+02	7.649E+00	2.193E+01	2.409E+01	4.346E+02	2.040E+01	01054634
010-020	8.122E-01	1.111E+02	4.146E+01	6.851E-01	1.770E+00	2.009E+00	3.883E+01	1.950E+00	01054771
020-030	9.194E-02	6.932E+00	2.365E+00	<2.469E-02	3.724E-02	4.734E-02	-	<4.260E-02	01054872

PROFILE BIKINI 503

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.045E+00	6.869E+01	8.617E+01	1.398E+00	3.327E+00	3.718E+00	7.527E+01	3.495E+00	01052331
005-010	8.748E-01	1.204E+02	7.378E+01	2.061E-01	9.770E-01	1.229E+00	2.556E+01	1.164E+00	01052434
010-020	1.426E-01	7.036E+01	9.719E+00	<4.423E-02	1.212E-01	1.466E-01	2.700E+00	<8.077E-02	01052571

PROFILE BIKINI 504

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	4.100E+00	2.208E+02	2.224E+02	5.545E+00	1.262E+01	1.396E+01	2.523E+02	1.446E+01	01049231
005-010	3.942E+00	2.458E+02	1.880E+02	5.514E+00	1.153E+01	1.297E+01	2.345E+02	1.435E+01	01049334
010-020	3.188E-01	2.826E+01	2.687E+01	1.696E-01	6.860E-01	7.982E-01	1.660E+01	6.306E-01	01049471
020-030	5.468E-02	7.973E+00	8.955E+00	<2.961E-02	1.236E-01	1.593E-01	-	<5.721E-02	01049572
030-040	<3.114E-02	-	5.532E+00	<2.473E-02	-	-	-	<4.291E-02	01049673
040-050	<4.314E-02	-	5.198E+00	<3.410E-02	-	-	-	<5.550E-02	01049774

PROFILE BIKINI 505

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.996E+00	1.157E+02	1.653E+02	2.619E+00	6.117E+00	6.766E+00	1.256E+02	6.590E+00	01053431
005-010	1.142E+00	1.000E+02	7.968E+01	1.559E+00	5.369E+00	5.878E+00	1.427E+02	4.559E+00	01053534
010-020	1.918E+00	1.226E+02	6.955E+01	2.973E+00	7.162E+00	7.793E+00	2.045E+02	7.532E+00	01053671
020-030	<2.893E-02	4.148E+00	1.689E+00	<2.291E-02	7.428E+00	8.171E+00	1.482E+02	<4.132E-02	01053772
030-040	<2.561E-02	-	4.266E-01	<1.949E-02	-	-	-	<3.436E-02	01053873
040-050	<1.698E-02	-	8.275E-01	<4.015E-02	-	-	-	<6.041E-02	01053974

PROFILE BIKINI 506

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	2.672E+00	1.937E+02	1.295E+02	3.092E+00	6.842E+00	7.554E+00	1.444E+02	7.671E+00	01055631
005-010	2.360E+00	2.143E+02	1.328E+02	2.805E+00	7.243E+00	8.027E+00	1.469E+02	7.293E+00	01055734
010-020	3.164E+00	1.940E+02	1.694E+02	3.525E+00	6.640E+00	7.360E+00	1.565E+02	9.707E+00	01055871
020-030	1.851E+00	1.585E+02	9.811E+01	2.016E+00	5.176E+00	5.712E+00	1.030E+02	4.883E+00	01055972
030-040	1.601E+00	1.529E+02	9.995E+01	2.102E+00	5.063E+00	5.595E+00	1.120E+02	5.428E+00	01056073
040-050	1.695E+00	1.426E+02	8.899E+01	1.988E+00	4.622E+00	5.113E+00	9.288E+01	4.870E+00	01056174
050-060	2.452E-01	6.311E+01	9.919E+00	1.314E-01	4.178E-01	4.694E-01	1.058E+01	5.378E-01	01056275

PROFILE BIKINI 507

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	3.411E+00	2.681E+02	1.337E+02	4.358E+00	1.000E+01	1.086E+01	1.960E+02	1.151E+01	01050331
005-010	1.583E+00	1.687E+02	8.410E+01	1.849E+00	4.368E+00	4.730E+00	8.851E+01	4.554E+00	01050434
010-020	1.180E-01	1.824E+01	2.149E+01	<5.153E-02	2.189E-01	2.571E-01	-	1.836E-01	01050571
020-030	<3.806E-02	8.901E-01	3.829E+00	<3.120E-02	-	-	-	<5.239E-02	01050672

PROFILE BIKINI 508

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	2.768E+00	1.990E+02	1.113E+02	3.413E+00	7.554E+00	8.095E+00	1.468E+02	8.730E+00	01051431
005-010	3.582E+00	2.325E+02	1.344E+02	4.273E+00	9.514E+00	1.023E+01	1.886E+02	1.046E+01	01051534
010-020	3.898E+00	2.979E+02	1.395E+02	4.450E+00	9.802E+00	1.062E+01	1.900E+02	1.148E+01	01051671
020-030	5.626E+00	4.192E+02	1.489E+02	7.095E+00	1.492E+01	1.597E+01	2.886E+02	1.795E+01	01051772
030-040	2.150E+00	1.970E+02	7.590E+01	2.925E+00	7.036E+00	7.365E+00	1.359E+02	6.604E+00	01051873
040-050	1.673E-01	9.770E+01	1.122E+01	<4.595E-02	2.141E-01	2.634E-01	5.775E+00	<8.477E-02	01051974

PROFILE ENEU 801

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.000E-01	4.200E+00	8.680E+00	1.623E-01	3.222E-01	3.506E-01	6.770E+00	2.783E-01	06088031
005-010	6.883E-02	3.518E+00	3.870E+00	7.050E-02	2.194E-01	2.392E-01	-	2.321E-01	06088134
010-020	1.415E-01	5.977E+00	4.374E+00	4.174E-01	8.347E-01	1.013E+00	-	7.667E-01	06088271
020-030	6.721E-02	2.405E+00	8.590E-01	<3.649E-02	1.694E-01	1.960E-01	-	1.122E-01	06088372
030-040	4.028E-02	2.245E+00	1.206E-01	<3.123E-02	-	-	-	<5.536E-02	06088473

PROFILE ENEU 802

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	<1.049E-02	1.376E+00	1.389E+00	<2.058E-02	2.554E-02	2.933E-02	7.396E-01	<3.750E-02	06090431
005-010	<2.291E-02	1.447E+00	1.280E+00	<2.386E-02	2.053E-02	1.977E-02	-	<3.769E-02	06090534
010-020	<8.991E-03	1.031E+00	1.236E+00	<2.459E-02	1.764E-02	1.949E-02	3.985E-01	<5.288E-02	06090671
020-030	<3.527E-02	6.838E-01	2.068E+00	<5.450E-02	6.005E-02	6.842E-02	1.354E+00	<9.734E-02	06090772
030-040	7.243E-02	9.779E-01	2.668E+00	<5.842E-02	1.198E-01	1.388E-01	-	<9.838E-02	06090873

PROFILE ENEU 803

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	2.489E-01	1.692E+01	1.073E+01	4.559E-01	1.160E+00	1.250E+00	2.267E+01	1.021E+00	06094631
005-010	2.432E-01	1.571E+01	1.034E+01	4.613E-01	1.160E+00	1.237E+00	2.396E+01	9.847E-01	06094734
010-020	2.691E-01	2.397E+01	8.743E+00	6.631E-01	1.279E+00	1.433E+00	-	1.318E+00	06094871
020-030	3.052E-01	2.930E+01	9.946E+00	6.743E-01	1.559E+00	1.654E+00	-	1.290E+00	06094972
030-040	3.271E-01	3.192E+01	1.109E+01	7.995E-01	1.939E+00	2.099E+00	4.055E+01	2.090E+00	06095073
040-050	2.232E-01	1.747E+01	1.035E+01	5.473E-01	1.138E+00	1.249E+00	3.631E+01	1.255E+00	06095174

PROFILE HFH2

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.116E-01	5.662E+00	2.991E+01	1.628E-01	3.957E-01	4.429E-01	-	4.267E-01	01056790
005-010	1.504E-01	6.041E+00	2.989E+01	1.928E-01	4.797E-01	5.338E-01	1.036E+01	5.622E-01	01056891
010-015	1.409E-01	5.333E+00	1.937E+01	1.912E-01	3.909E-01	4.464E-01	1.139E+01	4.100E-01	01056992
015-025	6.829E-02	6.243E+00	3.800E+00	1.177E-01	3.090E-01	3.637E-01	9.086E-01	2.738E-01	01057093
025-035	1.985E-01	-	3.576E+00	2.465E-01	-	-	-	6.279E-01	01057194
035-045	1.086E-01	-	2.969E+00	1.741E-01	-	-	-	2.814E-01	01057295

PROFILE HFH3

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.895E-01	1.735E+01	1.162E+01	2.850E-01	6.937E-01	7.545E-01	-	4.229E-01	01031390
005-010	1.132E-01	1.183E+01	5.315E+00	1.165E-01	2.838E-01	3.074E-01	5.950E+00	2.601E-01	01031491
010-015	1.927E-01	1.065E+01	8.117E+00	1.804E-01	3.960E-01	4.470E-01	-	3.490E-01	01031592
015-025	1.309E+00	7.730E+01	6.653E+01	1.892E+00	4.743E+00	5.293E+00	1.113E+02	4.577E+00	01031693
035-045	1.070E-01	1.352E+01	8.400E-01	2.966E-02	6.319E-02	7.293E-02	-	4.264E-02	01031895
045-055	1.158E-01	-	3.307E-01	<5.743E-02	-	-	-	<6.302E-02	01031996

PROFILE HFH4

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	8.838E-01	6.500E+01	4.275E+01	8.599E-01	2.024E+00	2.272E+00	5.622E+01	2.331E+00	01058390
005-010	4.177E-01	3.671E+01	1.656E+01	2.847E-01	9.162E-01	1.086E+00	2.071E+01	1.079E+00	01058491
010-015	1.708E-01	1.649E+01	5.072E+00	<3.336E-02	2.391E-01	3.150E-01	6.176E+00	1.974E-01	01058592
015-025	1.048E-01	1.809E+01	2.542E+00	<2.357E-02	1.740E-01	2.317E-01	-	1.860E-01	01058693
025-035	<2.822E-02	-	<2.429E-02	<1.896E-02	-	-	-	<3.231E-02	01058794
035-045	<1.782E-02	-	2.241E-01	<3.842E-02	-	-	-	<5.667E-02	01058895

PROFILE HFH5

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.854E+00	1.149E+02	8.162E+01	2.752E+00	6.545E+00	7.162E+00	1.287E+02	5.707E+00	01029890
005-010	7.423E+00	3.219E+02	1.401E+02	1.283E+01	3.202E+01	3.351E+01	5.959E+02	2.841E+01	01029991
010-015	3.173E+00	2.350E+02	1.284E+02	4.301E+00	1.031E+01	1.117E+01	2.867E+02	9.477E+00	01030092
015-025	6.541E-02	4.793E+01	4.761E+00	<2.122E-02	4.883E-02	5.730E-02	1.162E+00	<3.274E-02	01030193
025-035	<3.274E-02	-	4.241E-01	<2.227E-02	-	-	-	<3.768E-02	01030294
035-045	<3.041E-02	-	4.824E-01	<2.189E-02	-	-	-	<3.730E-02	01030496

PROFILE TS0001

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	8.829E-01	6.338E+01	5.414E+01	1.562E+00	3.391E+00	3.683E+00	6.572E+01	4.173E+00	01000190
005-010	8.554E-01	6.230E+01	4.883E+01	1.381E+00	3.114E+00	3.478E+00	8.288E+01	3.548E+00	01000291
010-015	1.176E+00	8.554E+01	4.676E+01	1.814E+00	4.206E+00	4.667E+00	8.613E+01	5.239E+00	01000392
015-020	1.814E+00	1.175E+02	4.770E+01	2.851E+00	6.464E+00	7.198E+00	1.327E+02	6.604E+00	01000401
020-025	1.463E+00	8.770E+01	3.266E+01	1.851E+00	4.923E+00	5.131E+00	9.563E+01	4.069E+00	01000501
025-030	2.264E+00	1.201E+02	2.271E+01	3.908E+00	8.928E+00	9.550E+00	1.762E+02	7.928E+00	01000601
030-040	<3.828E-02	3.669E+01	8.041E+00	<6.559E-02	6.198E-02	7.230E-02	-	<1.328E-01	01000701
040-045	-	2.453E+01	-	-	6.743E-02	9.185E-02	-	-	01000801

PROFILE TS0002

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	9.536E-01	4.797E+01	4.923E+01	1.385E+00	3.344E+00	3.672E+00	6.820E+01	2.979E+00	01006301
005-010	9.221E-01	5.743E+01	3.216E+01	1.187E+00	3.257E+00	3.642E+00	6.982E+01	2.749E+00	01006401
010-015	8.777E-01	6.022E+01	1.780E+01	1.383E+00	3.398E+00	3.778E+00	7.003E+01	3.202E+00	01006501
015-025	2.162E+00	2.015E+02	2.724E+01	3.900E+00	7.626E+00	8.378E+00	1.528E+02	8.122E+00	01006601
025-035	2.447E-01	6.541E+01	3.598E+00	2.014E-01	4.905E-01	5.252E-01	1.194E+01	4.284E-01	01006701

PROFILE TS0003

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	5.748E-01	4.389E+01	5.568E+01	8.554E-01	2.042E+00	2.300E+00	3.881E+01	1.818E+00	01106701
005-010	5.914E-01	4.040E+01	4.644E+01	8.811E-01	2.319E+00	2.543E+00	4.743E+01	1.814E+00	01106801
010-015	1.779E+00	9.928E+01	5.802E+01	3.255E+00	6.090E+00	6.779E+00	1.222E+02	6.946E+00	01006901
015-025	3.173E+00	2.433E+02	3.406E+01	4.352E+00	1.024E+01	1.127E+01	2.538E+02	9.432E+00	01007001
025-035	1.142E+00	1.400E+02	3.318E+01	1.321E+00	3.831E+00	3.981E+00	7.662E+01	2.945E+00	01007101
035-045	-	3.404E+01	-	-	4.277E-01	5.050E-01	-	-	01007201

PROFILE TS0012

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.830E+00	1.911E+02	1.243E+02	2.649E+00	6.595E+00	7.293E+00	1.397E+02	5.464E+00	01010901
005-010	2.324E+00	1.961E+02	1.021E+02	3.145E+00	7.410E+00	8.203E+00	1.574E+02	8.811E+00	01011101
015-020	2.381E+00	2.034E+02	9.572E+01	3.791E+00	9.176E+00	9.964E+00	1.851E+02	1.060E+01	01011201
020-033	9.140E-01	8.869E+01	4.946E+00	1.301E+00	2.948E+00	3.395E+00	7.964E+01	2.772E+00	01011301
036-051	1.062E+00	3.014E+02	9.955E+01	9.631E-01	2.460E+00	2.671E+00	4.856E+01	2.131E+00	01011401
056-102	1.800E-02	1.207E+00	1.742E+00	<1.035E-02	1.338E-02	1.500E-02	-	<1.667E-02	01011501

PROFILE TS0031

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	2.331E-01	2.757E+01	2.193E+01	2.991E-01	5.833E-01	6.883E-01	1.429E+01	7.045E-01	01004590
005-010	6.568E-01	5.527E+01	4.224E+01	5.595E-01	1.606E+00	1.845E+00	3.701E+01	1.945E+00	01004691
010-015	2.483E-01	3.643E+01	2.295E+01	1.774E-01	5.149E-01	5.712E-01	-	5.297E-01	01004792
015-025	1.741E-02	5.081E-01	1.498E+00	<1.814E-02	-	-	-	<2.913E-02	01004893
025-035	<2.910E-02	-	1.262E-01	<1.509E-02	-	-	-	<2.558E-02	01004994
035-045	<2.288E-02	<9.009E-01	1.103E-01	<1.581E-02	8.491E-04	7.667E-04	-	<2.886E-02	01005095

PROFILE TS0041

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	2.516E-01	1.973E+01	1.734E+01	2.541E-01	6.761E-01	7.626E-01	-	6.126E-01	01002090
005-010	1.127E+00	4.950E+01	6.401E+01	1.318E+00	3.278E+00	3.691E+00	6.671E+01	2.936E+00	01002191
010-015	1.270E+00	3.368E+01	7.009E+01	1.242E+00	3.627E+00	4.234E+00	-	2.983E+00	01002292
015-025	2.064E-01	4.088E+01	1.295E+01	<7.730E-02	9.041E-02	1.130E-01	-	<1.106E-01	01002393
025-035	<7.041E-02	5.653E+00	1.022E+01	<4.092E-02	3.256E-02	3.532E-02	-	<6.505E-02	01002494
035-045	<4.441E-02	<9.009E-01	4.104E+00	<2.522E-02	4.905E-03	6.302E-03	-	<3.990E-02	01002595

PROFILE TS0051

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	2.416E+00	1.950E+02	1.229E+02	3.636E+00	7.878E+00	8.770E+00	-	6.892E+00	01003590
005-010	2.932E+00	2.032E+02	1.410E+02	3.870E+00	9.477E+00	1.050E+01	2.013E+02	8.329E+00	01003691
010-015	3.166E+00	2.420E+02	1.437E+02	4.426E+00	9.973E+00	1.117E+01	-	8.905E+00	01003792
015-025	3.004E+00	1.882E+02	1.748E+02	4.216E+00	9.302E+00	1.043E+01	-	9.054E+00	01003893
025-035	3.200E+00	2.097E+02	1.907E+02	4.432E+00	9.622E+00	1.068E+01	-	8.797E+00	01003994
035-045	2.865E+00	2.186E+02	1.824E+02	3.988E+00	9.288E+00	1.036E+01	2.137E+02	8.324E+00	01004095

PROFILE TS0061

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	2.722E-01	5.122E+01	3.674E+01	5.059E-01	1.031E+00	1.142E+00	2.340E+01	9.284E-01	01008790
005-010	1.588E-01	1.769E+01	1.171E+01	3.266E-01	6.511E-01	7.159E-01	1.760E+01	7.197E-01	01008891
010-015	7.739E-02	7.518E+00	6.360E+00	1.100E-01	2.480E-01	2.801E-01	-	2.527E-01	01008992
015-025	1.855E+00	1.350E+02	8.252E+01	2.759E+00	6.198E+00	6.829E+00	1.294E+02	6.014E+00	01009093
025-035	4.626E+00	4.087E+02	2.190E+02	6.743E+00	1.657E+01	1.831E+01	3.330E+02	1.336E+01	01009194
035-045	5.604E+00	4.761E+02	3.393E+02	8.369E+00	1.729E+01	1.909E+01	3.495E+02	1.794E+01	01009295
045-055	3.285E+00	4.311E+02	1.350E+02	5.432E+00	1.104E+01	1.217E+01	2.263E+02	1.159E+01	01009396
055-065	3.212E-01	2.700E+02	2.432E+01	<7.117E-02	2.686E-01	2.943E-01	-	<1.116E-01	01009497
065-075	8.162E-02	5.324E+01	1.571E+00	2.708E-02	8.563E-03	1.001E-02	1.787E-01	<1.875E-02	01009598

PROFILE TS0062

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	8.162E-01	7.838E+01	5.833E+01	1.091E+00	2.539E+00	2.812E+00	5.252E+01	3.146E+00	01001190
005-010	5.387E-01	3.867E+01	2.744E+01	7.554E-01	1.744E+00	2.008E+00	-	1.979E+00	01001291
010-015	1.159E-01	7.892E+01	3.134E+00	4.191E-01	6.077E-01	6.563E-01	1.196E+01	5.081E-01	01001392
015-025	1.329E+00	7.622E+01	7.694E+01	2.023E+00	4.689E+00	5.167E+00	9.694E+01	4.054E+00	01001493
025-035	1.577E+00	1.493E+02	1.354E+02	1.767E+00	4.703E+00	5.347E+00	-	4.779E+00	01001594
035-045	1.575E-01	6.608E+01	1.616E+01	<8.284E-02	7.842E-02	1.021E-01	-	<1.245E-01	01001695

PROFILE TS0071

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.074E+00	1.071E+02	6.622E+01	1.412E+00	3.150E+00	3.594E+00	7.365E+01	3.610E+00	01005590
005-010	1.238E+00	1.140E+02	6.734E+01	1.600E+00	3.971E+00	4.382E+00	7.892E+01	4.716E+00	01005691
010-015	1.123E+00	1.046E+02	6.018E+01	1.667E+00	3.486E+00	3.886E+00	7.225E+01	4.079E+00	01006292
015-025	-	1.686E+02	-	-	6.662E+00	7.455E+00	1.429E+02	7.779E+00	01005792
025-035	-	7.943E+01	-	-	2.800E-01	3.616E-01	8.450E+00	-	01005893
035-045	-	4.963E+00	-	-	3.534E-02	4.308E-02	1.492E+00	-	01005994

PROFILE TS0081

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	6.707E-01	5.977E+01	3.821E+01	1.008E+00	1.952E+00	2.207E+00	4.640E+01	2.355E+00	01007490
005-010	2.109E+00	1.461E+02	8.149E+01	3.045E+00	7.108E+00	8.050E+00	1.769E+02	8.775E+00	01007591
010-015	2.968E+00	3.504E+02	1.036E+02	3.758E+00	1.036E+01	1.161E+01	2.409E+02	1.334E+01	01007692
015-025	3.510E-01	1.012E+02	2.183E+01	2.151E-01	5.883E-01	7.090E-01	1.410E+01	6.072E-01	01007793
025-035	7.757E-02	4.752E+01	6.144E+00	<3.423E-02	9.982E-02	1.282E-01	-	<6.086E-02	01007894
035-045	9.833E-02	2.414E+01	2.506E+00	<1.721E-02	7.910E-02	1.058E-01	-	8.779E-02	01007995
105-115	1.275E+00	9.991E+01	5.613E+01	2.305E+00	4.073E+00	4.391E+00	8.239E+01	4.354E+00	01008601

PROFILE TS0091

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	7.054E-01	4.389E+01	7.604E+01	1.126E+00	2.590E+00	2.943E+00	7.986E+01	3.207E+00	01028690
005-010	1.547E+00	8.883E+01	9.464E+01	1.925E+00	5.333E+00	5.964E+00	1.075E+02	6.054E+00	01028791
010-015	2.241E+00	1.301E+02	8.869E+01	3.482E+00	8.207E+00	9.212E+00	2.026E+02	9.464E+00	01028892
015-025	4.847E-01	8.356E+01	2.818E+01	3.001E-01	9.059E-01	1.073E+00	-	9.955E-01	01028993
025-035	1.619E-01	5.275E+01	7.072E+00	<7.311E-02	2.614E-01	3.117E-01	6.874E+00	2.877E-01	01029094
035-045	<3.901E-02	6.243E+00	2.636E+00	<2.936E-02	2.947E-02	3.685E-02	-	<4.653E-02	01029195
045-055	<2.391E-02	-	1.309E+00	<2.023E-02	-	-	-	<3.097E-02	01029296

PROFILE TS0101

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	3.694E-01	7.905E+01	5.640E+01	4.937E-01	1.185E+00	1.319E+00	2.447E+01	1.374E+00	01035290
005-010	2.548E-01	4.991E+01	3.317E+01	2.854E-01	7.279E-01	8.441E-01	2.003E+01	7.991E-01	01035391
010-015	1.422E-01	3.244E+01	1.438E+01	7.946E-02	2.578E-01	2.864E-01	4.959E+00	2.747E-01	01035492
015-025	<3.252E-02	1.850E+01	<1.404E-01	<3.933E-02	-	-	-	<6.144E-02	01035593
025-035	<3.123E-02	6.302E+00	8.468E-01	<2.423E-02	1.060E-02	1.334E-02	-	<4.078E-02	01035694
035-045	<2.829E-02	3.993E+00	2.062E-01	<2.292E-02	-	-	-	<3.812E-02	01035795

PROFILE TS0111

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	6.153E-01	6.396E+01	7.946E+01	7.667E-01	2.147E+00	2.385E+00	5.162E+01	2.677E+00	01011990
005-010	9.784E-01	9.523E+01	9.968E+01	1.637E+00	3.474E+00	3.869E+00	7.977E+01	4.039E+00	01012091
010-015	1.600E+00	8.194E+01	1.271E+02	2.015E+00	5.356E+00	5.973E+00	1.143E+02	6.631E+00	01012192
015-025	1.074E+00	8.338E+01	7.086E+01	1.038E+00	3.150E+00	3.577E+00	-	2.554E+00	01012293
025-035	3.204E-02	3.616E+01	3.063E+00	<1.523E-02	2.776E-02	3.598E-02	-	<3.155E-02	01012394
035-045	<2.958E-02	7.306E+00	2.603E+00	<2.286E-02	-	-	-	<3.926E-02	01012495

A-16

PROFILE TS0121

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.691E+00	1.380E+02	1.10[illegible]+02	2.341E+00	5.590E+00	6.185E+00	1.245E+02	6.131E+00	01032990
005-010	1.932E+00	2.343E+02	1.091E+02	2.818E+00	6.860E+00	7.590E+00	1.403E+02	9.671E+00	01033091
010-015	3.823E+00	3.183E+02	1.777E+02	6.059E+00	1.400E+01	1.514E+01	2.673E+02	1.874E+01	01033192
015-025	2.137E-01	2.304E+01	1.197E+01	<6.131E-02	2.422E-01	2.827E-01	-	2.601E-01	01033293
025-035	5.032E-01	1.240E+02	3.888E+01	1.783E-01	8.865E-01	1.087E+00	2.259E+01	9.811E-01	01033394
035-045	1.347E-01	1.231E+01	9.739E+00	<4.802E-02	1.281E-01	1.487E-01	-	1.958E-01	01033495
045-055	6.243E-02	2.493E+00	6.977E+00	<1.455E-02	4.323E-02	4.955E-02	1.122E+00	<2.944E-02	01033596

PROFILE TS0131

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	5.689E+00	3.421E+02	3.404E+02	7.559E+00	1.806E+01	2.033E+01	3.914E+02	2.383E+01	01034190
005-010	1.164E+00	1.689E+02	6.374E+01	1.081E+00	2.488E+00	2.886E+00	5.275E+01	3.433E+00	01034291
010-015	3.530E-01	1.279E+02	1.269E+01	<1.073E-01	4.047E-01	4.892E-01	8.950E+00	4.577E-01	01034392
015-025	<3.644E-02	2.570E+01	1.263E+00	<3.121E-02	4.860E-02	6.153E-02	1.272E+00	<5.234E-02	01034493
025-035	<2.962E-02	-	3.174E-01	<1.845E-02	-	-	-	<3.118E-02	01034594
035-045	<3.832E-02	2.725E+00	2.770E-01	<2.029E-02	3.036E-02	3.586E-02	-	<3.728E-02	01034695
125-145	<1.[illegible]E-02	<3.604E+00	<1.614E-02	<1.365E-02	-	-	-	<2.359E-02	01035101

PROFILE TS0161

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	4.068E-01	1.944E+01	5.658E+01	4.068E-01	1.114E+00	1.251E+00	2.686E+01	1.236E+00	01038290
005-010	5.977E-01	2.055E+01	3.322E+01	6.437E-01	1.442E+00	1.740E+00	-	1.655E+00	01038391
010-015	7.341E-01	3.382E+01	3.213E+01	7.821E-01	1.917E+00	2.118E+00	4.065E+01	2.209E+00	01038492
015-025	5.964E-01	3.122E+01	2.689E+01	6.284E-01	1.485E+00	1.675E+00	3.185E+01	1.641E+00	01038593
025-035	4.734E-01	4.104E+01	3.369E+01	5.829E-01	1.315E+00	1.482E+00	3.336E+01	1.498E+00	01038694
035-045	1.659E-01	2.481E+01	1.014E+01	1.391E-01	3.845E-01	4.383E-01	1.019E+01	4.236E-01	01038795
045-055	3.183E-01	3.909E+01	2.145E+01	5.077E-01	1.167E+00	1.273E+00	2.499E+01	1.112E+00	01038896
055-065	7.311E-02	2.249E+01	9.734E+00	<4.160E-02	2.327E-01	2.412E-01	-	1.661E-01	01038997
065-075	2.418E-01	2.220E+01	1.492E+01	2.116E-01	6.077E-01	6.869E-01	-	5.977E-01	01039098
075-085	1.774E-01	1.888E+01	1.039E+01	1.616E-01	4.384E-01	4.784E-01	1.011E+01	4.946E-01	01039199
085-095	1.251E-01	2.479E+01	1.273E+01	3.405E-01	8.041E-01	8.928E-01	-	8.658E-01	01039201
095-105	<4.389E-02	1.454E+01	7.014E+00	<3.660E-02	1.622E-01	1.760E-01	-	<6.667E-02	01039301
105-125	9.941E-01	4.429E+01	3.491E+01	1.295E+00	3.373E+00	3.727E+00	6.842E+01	3.258E+00	01039401
125-145	3.273E+00	1.808E+02	4.892E+01	4.644E+00	1.023E+01	1.087E+01	1.972E+02	1.178E+01	01039501
145-165	<6.432E-02	1.095E+01	6.964E+00	<3.911E-02	6.586E-02	8.216E-02	1.937E+00	<7.113E-02	01039601
165-185	<3.620E-02	<3.153E-01	1.146E+00	<2.190E-02	-	-	-	<3.980E-02	01039701

PROFILE TS0171

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.533E+00	1.360E+01	9.595E+01	2.206E+00	5.491E+00	6.212E+00	1.300E+02	6.667E+00	01027390
005-010	2.712E-01	5.063E+01	2.153E+01	<7.523E-02	4.748E-01	5.986E-01	-	5.423E-01	01027491
010-015	1.953E-01	4.138E+01	1.719E+01	<6.581E-02	3.323E-01	4.413E-01	8.955E+00	3.982E-01	01027592
015-025	1.796E-01	3.558E+01	4.095E+00	<5.441E-02	-	-	-	4.563E-01	01027693
025-035	7.023E-02	3.690E+00	1.407E+00	<3.935E-02	-	-	-	<6.851E-02	01027794
035-045	6.275E-02	3.438E+00	1.118E+00	<1.987E-02	-	-	-	1.592E-01	01027895

PROFILE TS0181

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.939E+00	1.202E+02	2.838E+01	2.257E+00	6.050E+00	6.640E+00	1.350E+02	6.010E+00	01062690
005-010	1.001E+00	9.784E+01	2.225E+01	9.557E-01	2.481E+00	2.800E+00	4.946E+01	2.605E+00	01062791
010-015	2.397E+00	1.732E+02	3.165E+01	2.836E+00	6.842E+00	7.617E+00	1.385E+02	7.218E+00	01062892
015-025	5.609E-01	6.063E+01	5.205E+00	1.433E-01	8.968E-01	1.134E+00	-	9.761E-01	01062993
025-035	1.479E-01	4.141E+01	1.398E+00	<3.397E-02	1.641E-01	2.128E-01	4.117E+00	1.614E-01	01063094
035-045	1.068E-01	3.374E+01	1.266E+00	<3.360E-02	1.545E-01	2.051E-01	3.832E+00	<6.023E-02	01063195
045-055	1.560E-01	6.252E+01	1.517E+01	5.523E-02	1.734E-01	2.326E-01	-	1.739E-01	01063296
055-065	<4.328E-02	2.918E+01	1.005E+01	<4.523E-02	7.932E-02	1.025E-01	1.910E+00	<7.878E-02	01063397
065-085	<5.306E-02	3.470E+00	1.503E+00	<2.426E-02	-	-	-	<4.505E-02	01063401

PROFILE TS0191

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	8.743E-01	4.950E+01	6.207E+01	1.181E+00	2.682E+00	3.135E+00	3.365E+01	3.109E+00	01060090
005-010	6.950E-01	5.117E+01	3.766E+01	1.044E+00	2.262E+00	2.529E+00	4.451E+01	2.420E+00	01060191
010-015	6.680E-01	4.806E+01	3.782E+01	8.104E-01	1.492E+00	1.697E+00	3.727E+01	2.013E+00	01060292
015-025	1.404E-01	2.204E+01	8.203E+00	1.249E-01	3.218E-01	4.127E-01	-	3.175E-01	01060393
025-035	2.829E-01	2.595E+01	2.228E+01	3.545E-01	8.635E-01	9.617E-01	1.800E+01	8.644E-01	01060494
035-045	1.614E-01	1.119E+01	5.955E+00	1.973E-01	4.388E-01	4.986E-01	-	4.842E-01	01060595
045-055	4.577E-01	4.060E+01	2.106E+01	4.901E-01	1.285E+00	1.475E+00	-	1.323E+00	01060695
055-065	8.595E-01	6.559E+01	4.649E+01	7.793E-01	2.006E+00	2.252E+00	4.323E+01	2.183E+00	01060797
065-075	1.712E+00	1.155E+02	5.023E+01	2.156E+00	4.946E+00	5.428E+00	-	4.869E+00	01060898
075-085	8.392E-01	8.829E+01	2.723E+01	6.964E-01	2.051E+00	2.380E+00	4.423E+01	2.159E+00	01060999
085-095	1.254E-01	3.598E+01	2.389E+01	1.231E-01	3.367E-01	3.762E-01	6.167E+00	4.027E-01	01061001
095-105	5.140E-02	9.279E+00	1.433E+01	5.739E-02	1.872E-01	2.080E-01	3.787E+00	2.439E-01	01061101
105-115	1.687E-01	1.499E+01	2.808E+01	1.776E-01	4.467E-01	5.207E-01	-	3.863E-01	01061201
115-125	<2.271E-02	2.384E+00	3.481E+00	<1.979E-02	4.568E-03	5.766E-03	-	<3.873E-02	01061301

PROFILE TS0201

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	9.937E-01	3.451E+01	5.027E+01	1.241E+00	2.926E+00	3.515E+00	7.482E+01	3.645E+00	01061590
005-010	1.149E+00	4.500E+01	2.882E+01	1.275E+00	3.740E+00	4.563E+00	8.973E+01	4.022E+00	01061691
010-015	4.761E-01	2.486E+01	1.514E+01	3.756E-01	9.673E-01	1.155E+00	2.188E+01	1.126E+00	01061792
015-025	5.455E-02	2.057E+01	1.002E+01	<3.528E-02	-	-	-	<6.568E-02	01061893
025-035	<5.225E-02	1.723E+01	7.171E+00	<3.464E-02	-	-	-	<7.027E-02	01061994
035-045	<2.385E-02	-	1.063E+00	<2.079E-02	-	-	-	<3.770E-02	01062095
045-055	<2.560E-02	-	5.964E-01	<1.922E-02	-	-	-	<3.550E-02	01062196

PROFILE TS0231

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	5.856E-01	2.997E+01	3.506E+01	7.239E-01	1.700E+00	1.896E+00	4.806E+01	1.957E+00	01036790
005-010	5.329E-02	1.078E+01	1.651E+01	<4.887E-02	2.152E-01	2.436E-01	5.856E+00	<8.464E-02	01036891
010-015	<8.532E-02	9.788E+00	4.106E+01	<6.437E-02	1.377E-01	1.532E-01	-	<1.167E-01	01036992
015-025	<3.628E-02	1.275E+01	4.408E+00	<3.018E-02	1.475E+00	1.653E+00	3.179E+01	<5.923E-02	01037093
025-035	<4.251E-02	1.088E+01	1.886E+00	<3.301E-02	2.904E-02	3.756E-02	-	<5.369E-02	01037194
035-045	<2.038E-02	3.343E+00	1.454E+00	<4.443E-02	8.559E-03	1.040E-02	-	<6.500E-02	01037295

PROFILE TS0241

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	6.473E-02	3.286E+00	6.068E+00	1.444E-01	1.826E+00	2.212E+00	3.336E+01	2.109E-01	06067890
005-010	6.014E-02	3.555E+00	2.915E+00	1.394E-01	2.663E-01	2.789E-01	5.622E+00	2.445E-01	06067991
010-015	8.766E-02	4.617E+00	2.336E+00	1.518E-01	3.093E-01	3.371E-01	7.775E+00	2.302E-01	06068092
015-025	9.320E-02	3.643E+00	3.020E+00	1.667E-01	2.982E-01	3.159E-01	-	3.940E-01	06068193
025-035	1.498E-01	5.432E+00	2.487E+00	2.574E-01	3.571E-01	3.917E-01	8.090E+00	5.050E-01	06068294
035-045	1.157E-01	7.428E+00	2.229E+00	1.952E-01	5.545E-01	5.955E-01	9.608E+00	4.475E-01	06068395

PROFILE TS0251

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.780E-01	8.779E+00	1.258E+01	1.778E-01	3.723E-03	4.977E-03	-	4.207E-01	06066490
005-010	1.893E-01	7.572E+00	7.356E+00	2.686E-01	4.577E-01	5.086E-01	-	4.323E-01	06066591
010-015	2.064E-01	8.239E+00	6.185E+00	4.306E-01	5.140E-01	5.577E-01	1.019E+01	8.505E-01	06066692
015-025	1.609E-01	6.207E+00	7.320E+00	2.743E-01	9.198E-01	1.048E+00	-	6.198E-01	06066793
025-035	2.093E-01	1.104E+01	3.476E+00	4.122E-01	6.662E-01	5.500E-01	-	9.329E-01	06066894
035-045	3.101E-01	1.797E+01	4.063E+00	6.306E-01	1.124E+00	1.282E+00	2.529E+01	1.451E+00	06066995

PROFILE TS0261

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.595E-01	4.689E+00	7.892E+00	1.339E-01	4.147E-01	4.775E-01	-	4.250E-01	06065290
005-010	1.714E-01	6.419E+00	3.718E+00	2.119E-01	4.304E-01	5.108E-01	1.099E+01	4.833E-01	06065391
010-015	1.820E-01	7.320E+00	3.703E+00	1.273E-01	5.171E-01	6.045E-01	-	4.396E-01	06065492
015-025	1.195E-01	1.137E+01	4.421E+00	<5.077E-02	3.477E-01	4.014E-01	-	3.377E-01	06065593
025-035	7.167E-02	8.608E+00	1.776E+00	<4.514E-02	5.689E-02	6.640E-02	-	<1.351E-02	06065694
035-045	<2.022E-02	4.395E+00	1.572E-01	<3.395E-02	-	-	-	<6.234E-02	06065795
045-055	<2.555E-02	2.903E-01	<2.413E-02	<1.532E-02	-	-	-	<2.670E-02	06065896
055-065	<1.574E-02	3.916E-01	<1.870E-02	<1.470E-02	2.965E-03	3.395E-03	-	<2.626E-02	06065901
065-085	<2.278E-02	<3.153E-01	<1.787E-02	<2.003E-02	-	-	-	<3.491E-02	06066001
085-105	<1.685E-02	<4.505E-01	<1.304E-02	<1.706E-02	-	-	-	<7.113E-02	06066101
105-125	<1.386E-02	<2.703E-01	<1.129E-02	<1.441E-02	-	-	-	<2.522E-02	06066201
125-145	<2.914E-02	<2.928E-01	<2.610E-02	<1.732E-02	-	-	-	<3.130E-02	06066301

PROFILE TS0271

CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	1.185E-01	2.428E+00	4.257E+00	9.541E-02	3.604E-01	4.093E-01	7.315E+00	2.480E-01	06089190
005-010	<3.403E-02	1.789E+00	1.605E+00	1.008E-01	3.768E-01	4.354E-01	8.505E+00	2.150E-01	06089291
010-015	1.109E-01	1.533E+00	1.121E+00	1.192E-01	4.159E-01	4.711E-01	9.383E+00	2.951E-01	06089392
015-025	<3.383E-02	4.123E-01	2.725E-01	<5.347E-02	-	-	-	<9.086E-02	06089493
025-035	5.716E-02	<3.153E-01	1.800E-01	<5.288E-02	-	-	-	<9.261E-02	06089594
035-045	<3.791E-02	<3.604E-01	1.194E-01	<5.671E-02	6.563E-03	6.946E-03	-	<8.766E-02	06089695

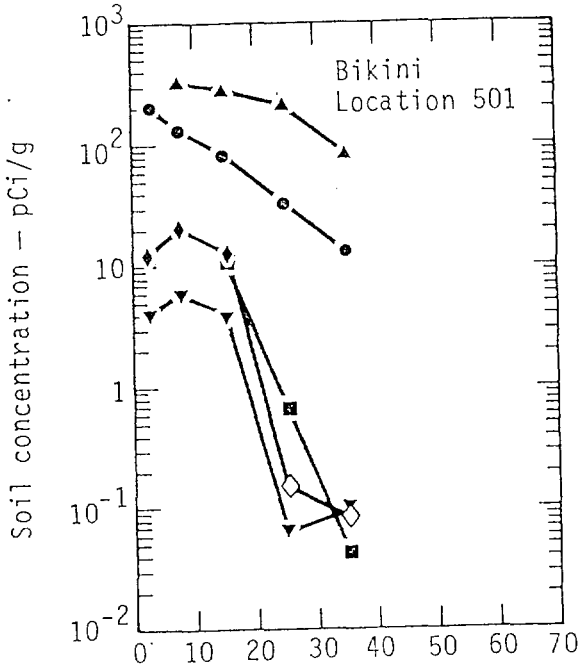
PROFILE TS0301

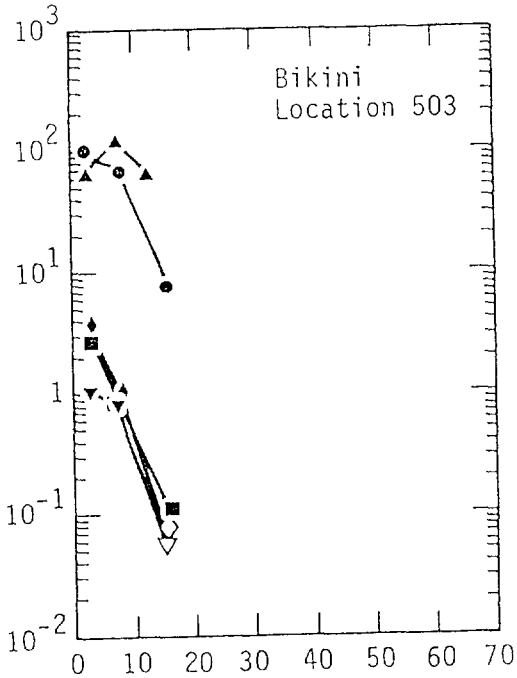
CONCENTRATIONS IN PCI/GM. MINUS FOR NO DATA. LESS THAN SIGN INDICATES INSTRUMENTAL DETECTION LIMIT

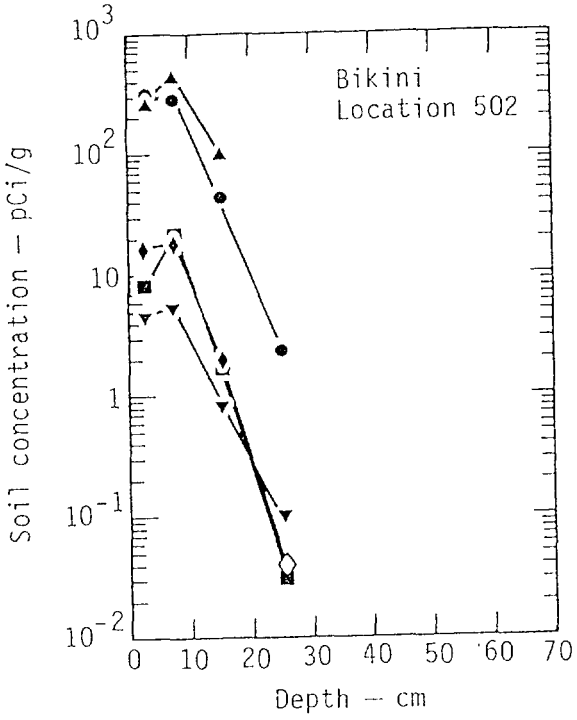
DEPTH(CM)	27 CO 60	38 SR 90	55 CS 137	63 EU 155	94 PU 239	94 PU 240	94 PU 241	95 AM 241	MASTER LOG
000-005	2.592E-01	1.776E+01	1.136E+01	5.649E-01	1.344E+00	1.444E+00	2.413E+01	1.023E+00	06093290
005-010	3.294E-01	1.574E+01	9.599E+00	4.761E-01	1.102E+00	1.218E+00	-	9.770E-01	06093391
010-015	3.338E-01	1.499E+01	9.770E+00	5.149E-01	1.093E+00	1.160E+00	2.315E+01	1.036E+00	06093492
015-025	2.459E-01	1.611E+01	1.055E+01	4.775E-01	1.023E+00	1.111E+00	2.023E+01	1.155E+00	06093593
025-035	5.541E-01	3.409E+01	1.778E+01	1.276E+00	2.888E+00	3.083E+00	5.658E+01	3.002E+00	06093694
035-045	3.004E-01	2.146E+01	9.856E+00	6.081E-01	1.244E+00	1.350E+00	-	9.239E-01	06093795

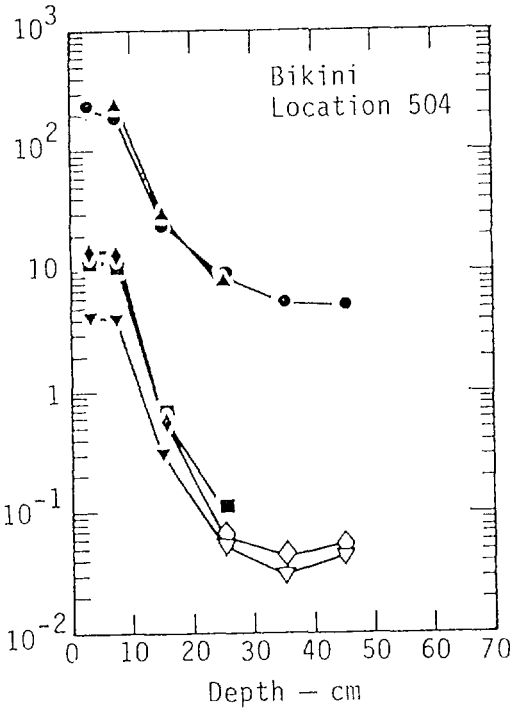
Appendix B. The Distribution of Radionuclides with Depth in Soil Profiles of Bikini and Eneu Islands

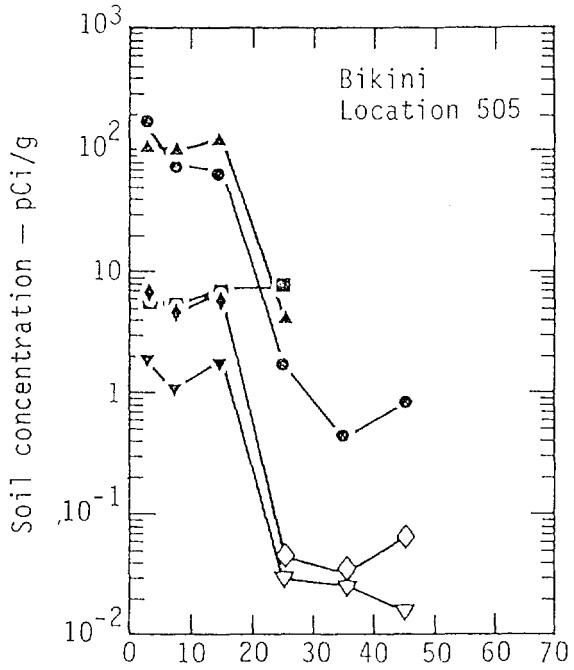
The following figures graphically present the concentrations of five selected radionuclides (^{60}Co, ^{90}Sr, ^{137}Cs, ^{239}Pu, and ^{231}Am) with depth of soil. One graph is given for each sample location of the islands (see Figs. 2, 3) and each corresponds to the tabular presentation of the same data in Appendix A. Throughout, open symbols indicate detection limits and solid symbols indicate measured values: ▼ = ^{60}Co, ▲ = ^{90}Sr, ● = ^{137}Cs, ■ = ^{239}Pu, and ◆ = ^{241}Am. Figures are grouped according to general location of the samples.

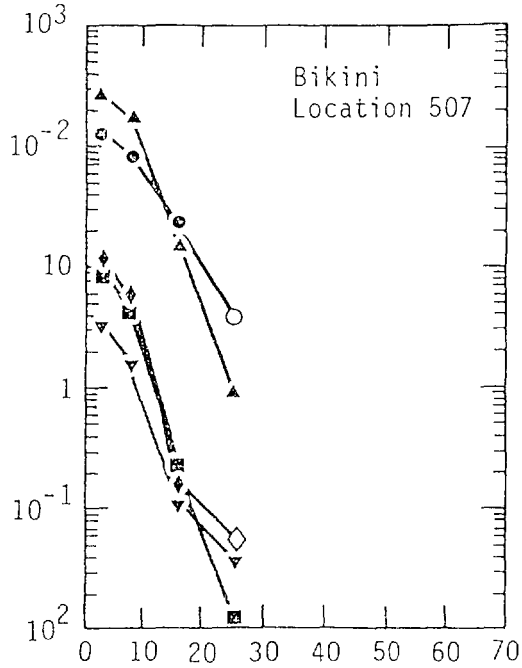


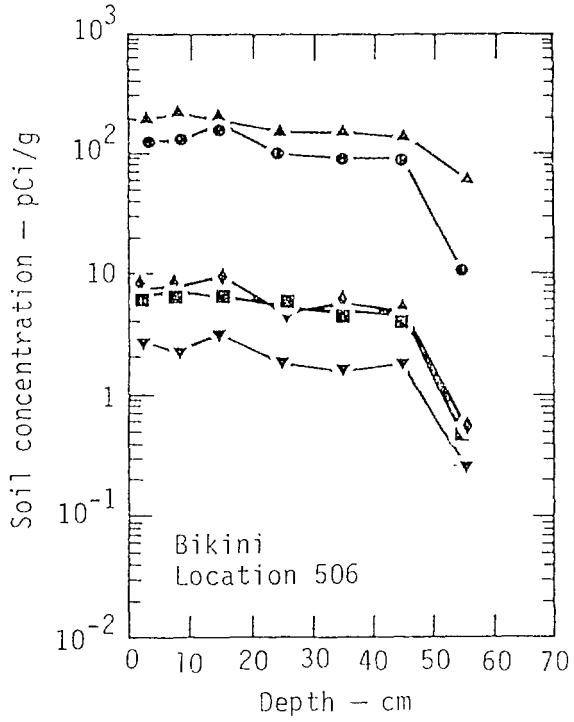


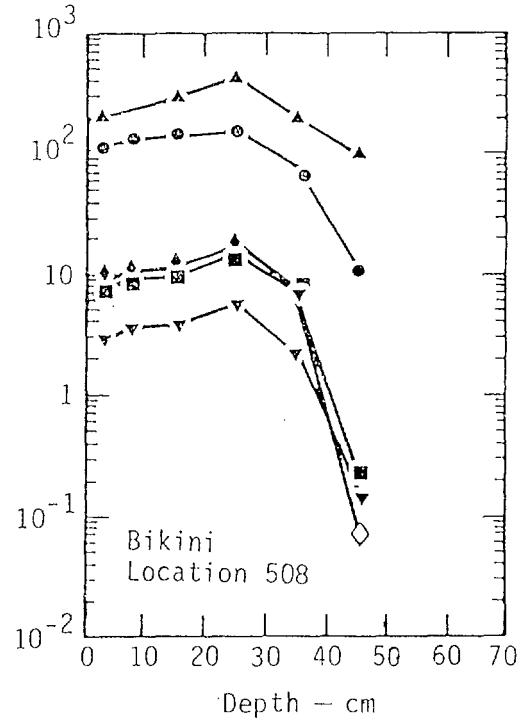


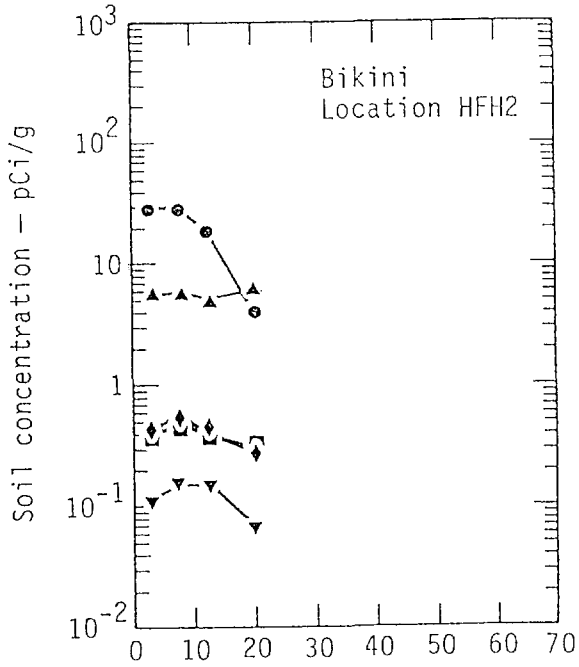


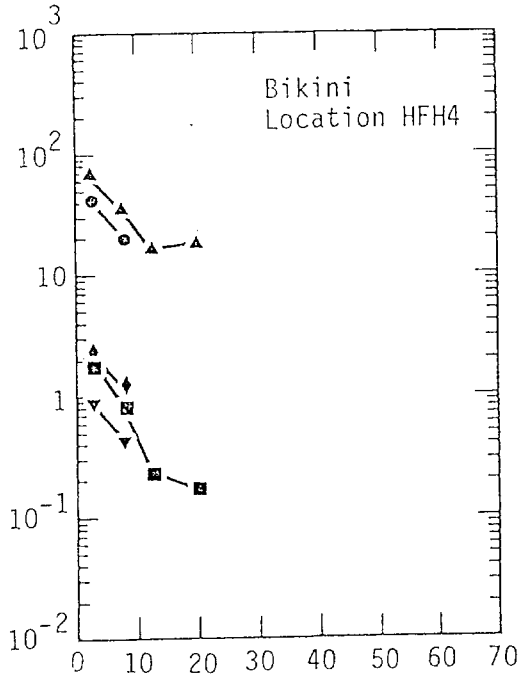

Bikini
Location 505
Soil concentration — pCi/g
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70

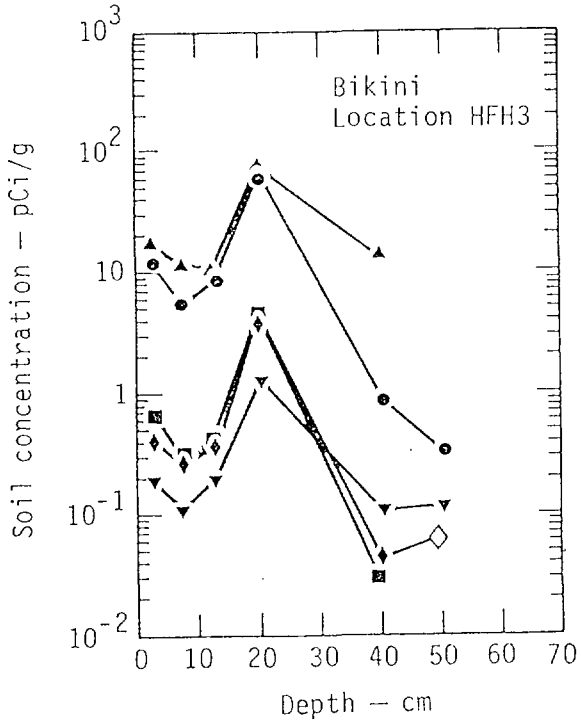

Bikini
Location 507
10^3
10^{-2}
10
1
10^{-1}
10^2
0 10 20 30 40 50 60 70

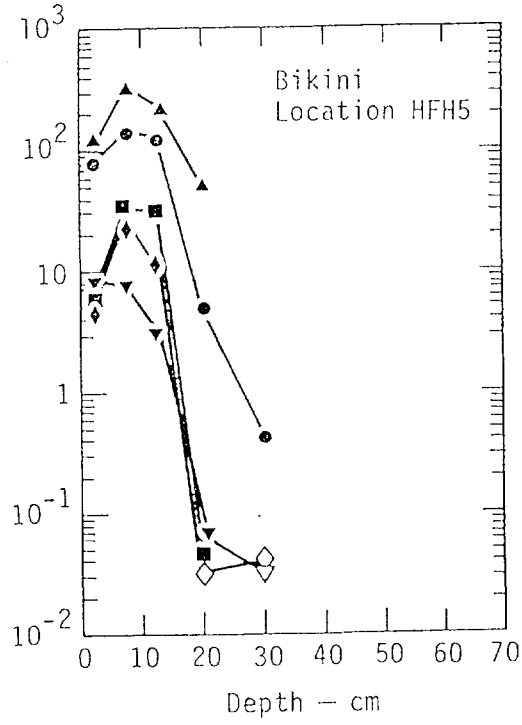

Bikini
Location 506
Soil concentration — pCi/g
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70
Depth — cm

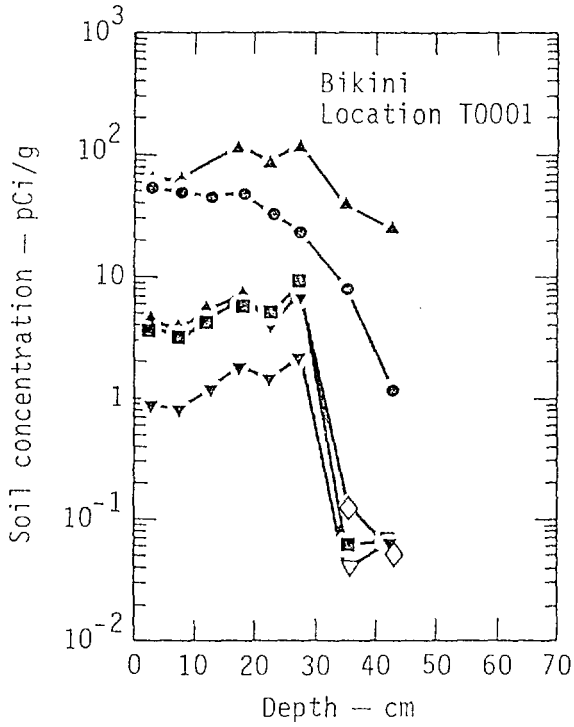

Bikini
Location 508
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70
Depth — cm

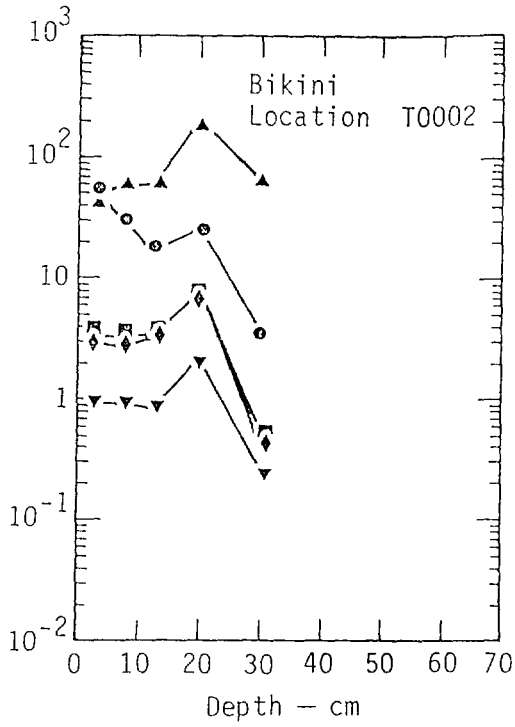

Bikini
Location HFH2
Soil concentration — pCi/g
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70

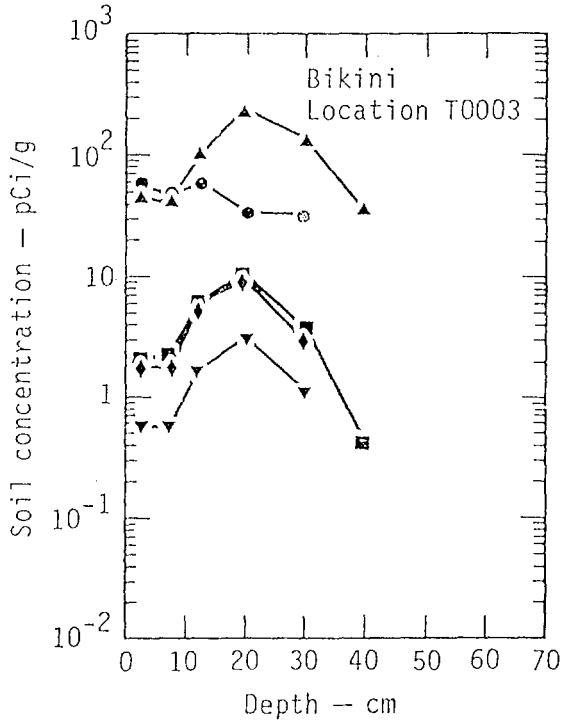

Bikini
Location HFH4
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70

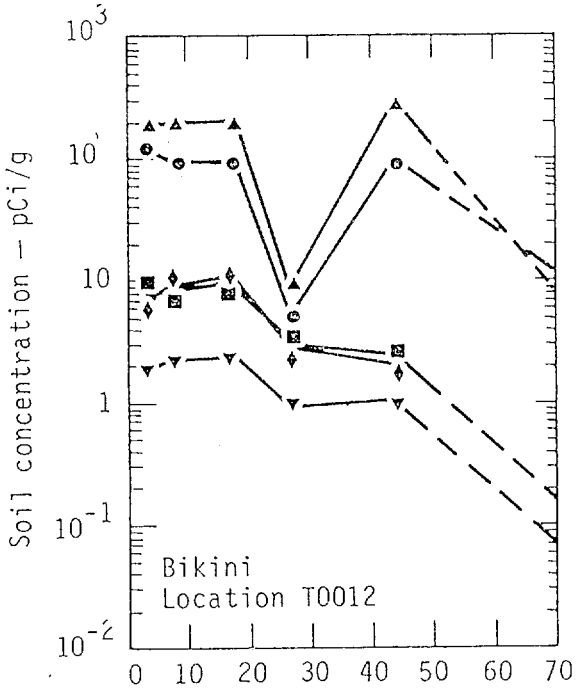

Bikini
Location HFH3
Soil concentration — pCi/g
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70
Depth — cm

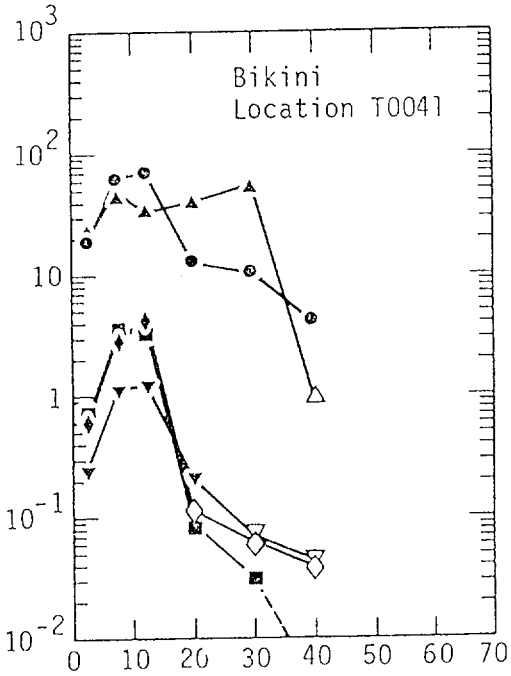

Bikini
Location HFH5
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70
Depth — cm

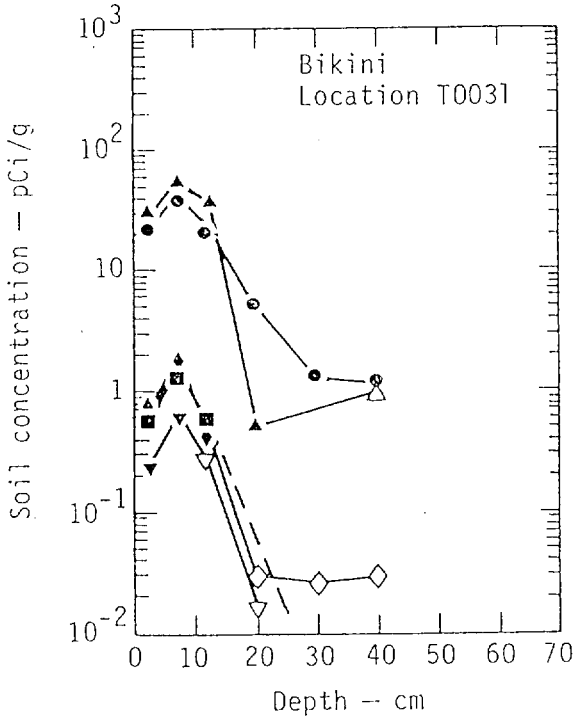

Bikini
Location T0001
Soil concentration — pCi/g
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70
Depth — cm

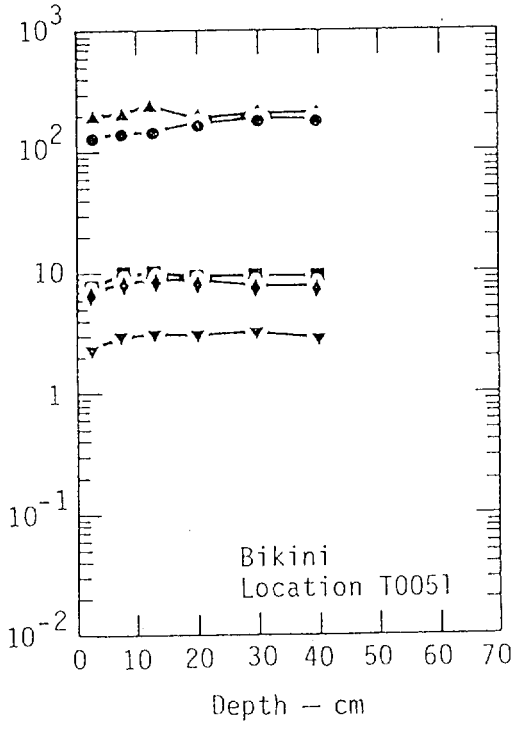

Bikini
Location T0002
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70
Depth — cm

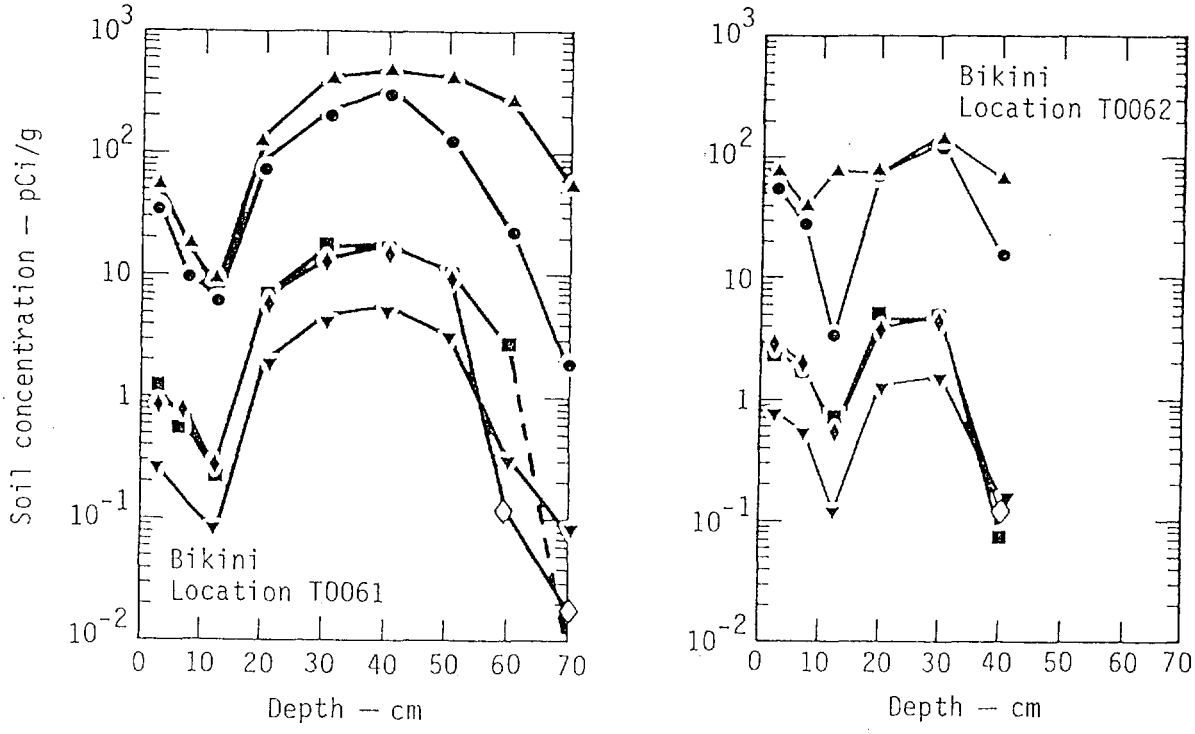

Bikini
Location T0003
Soil concentration — pCi/g
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70
Depth — cm

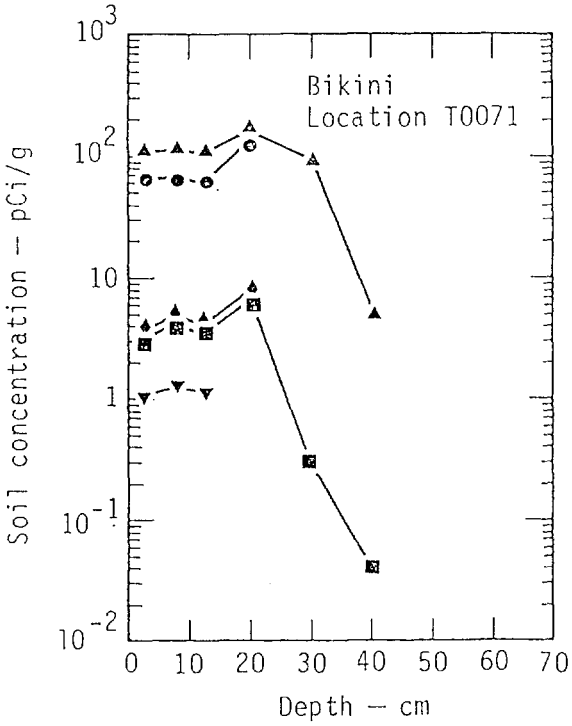

Soil concentration — pCi/g
Bikini
Location T0012

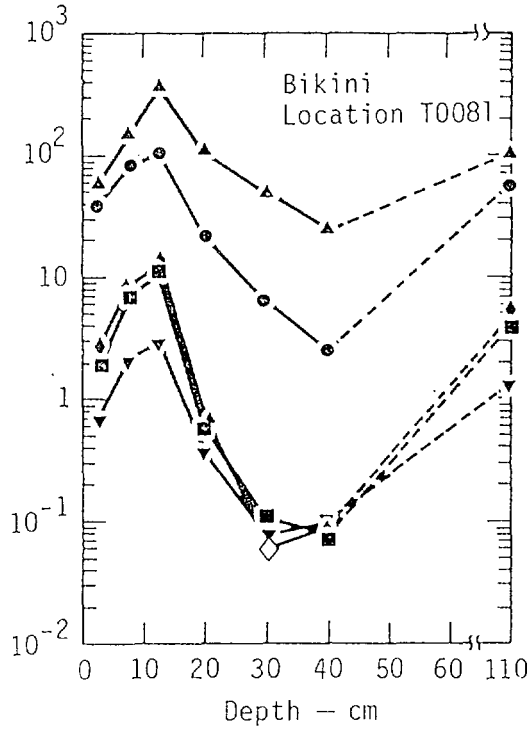

Bikini
Location T0041

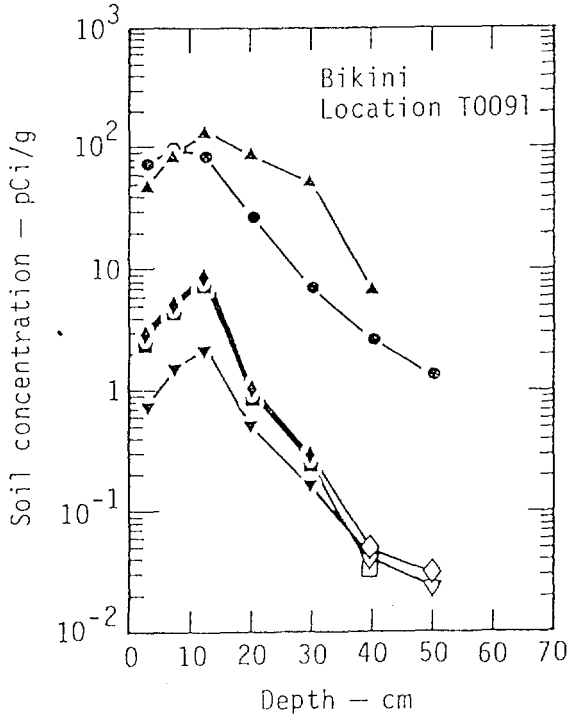

Soil concentration — pCi/g
Bikini
Location T0031
Depth — cm

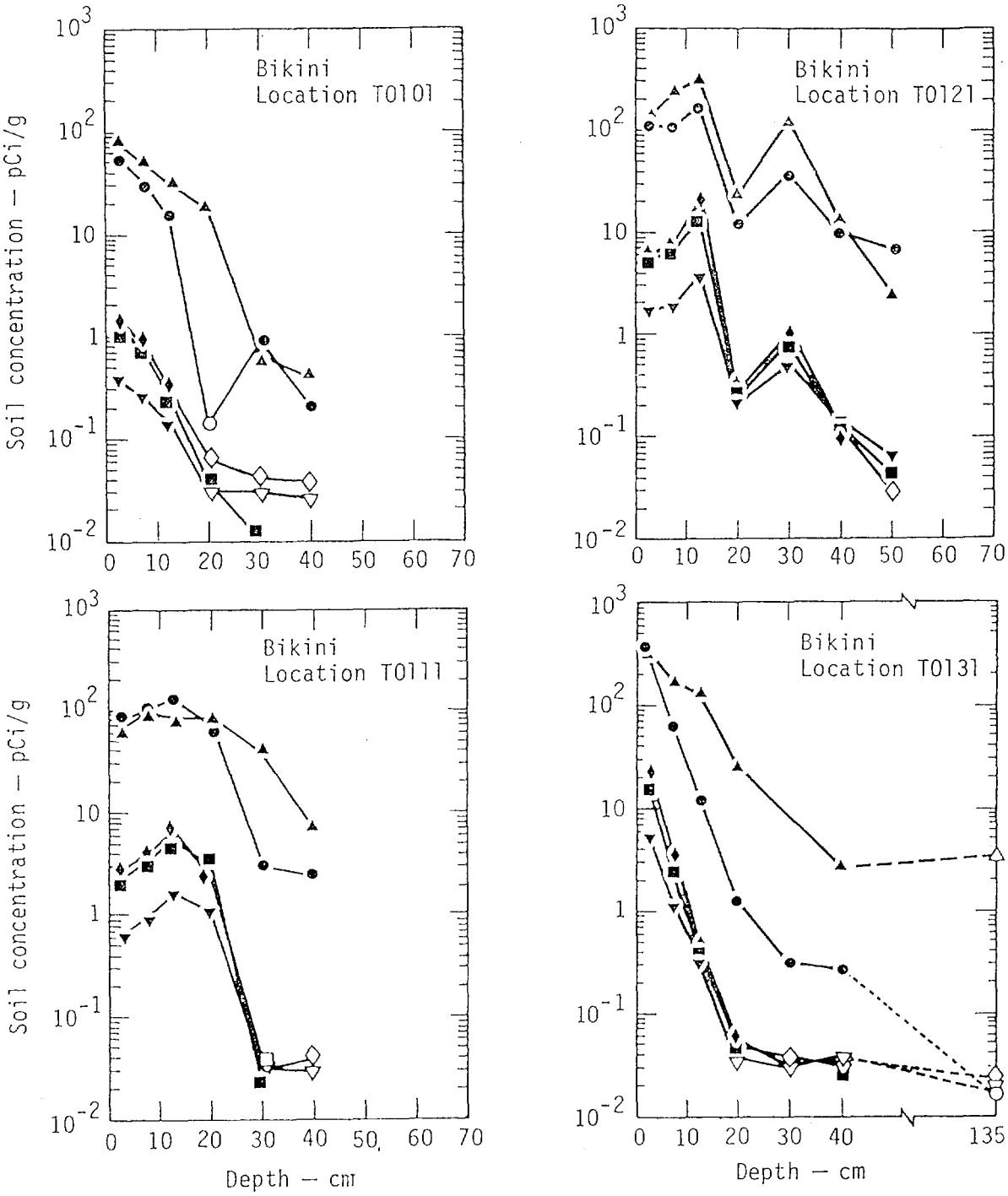

Bikini
Location T0051
Depth — cm

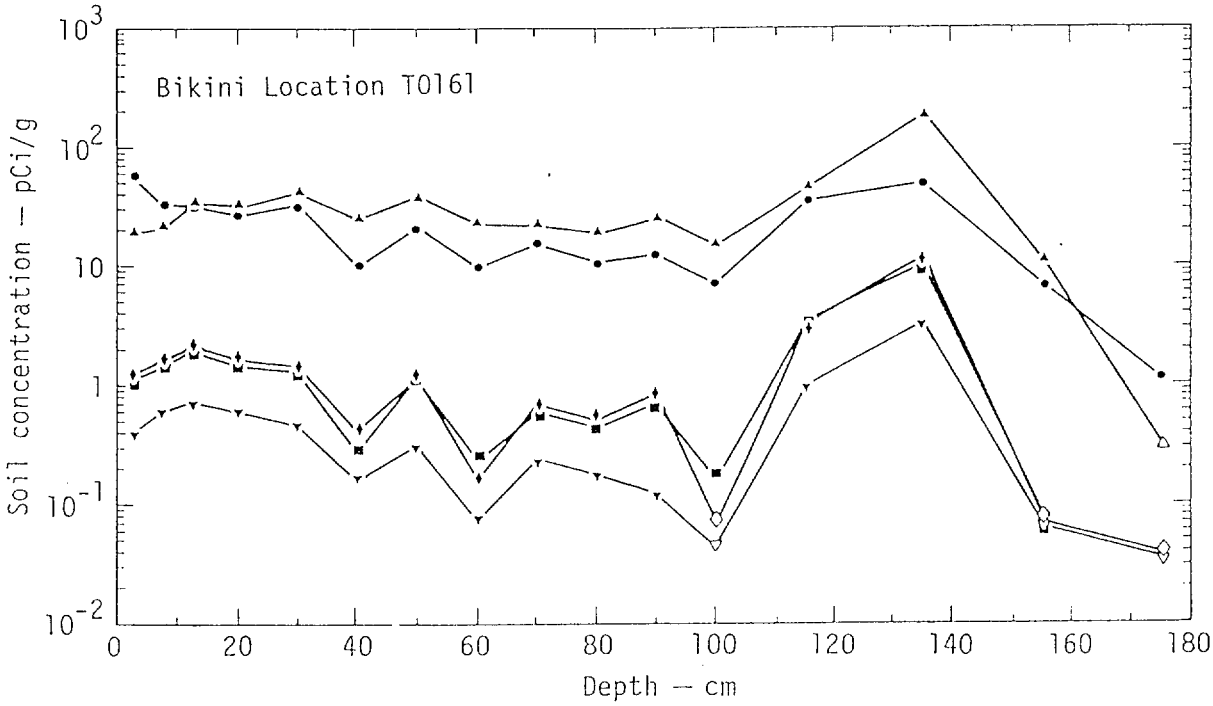

Soil concentration — pCi/g
10^3
10^2
10
1
10^{-1}
10^{-2}
Bikini
Location T0061
0 10 20 30 40 50 60 70
Depth — cm
Bikini
Location T0062
0 10 20 30 40 50 60 70
Depth — cm

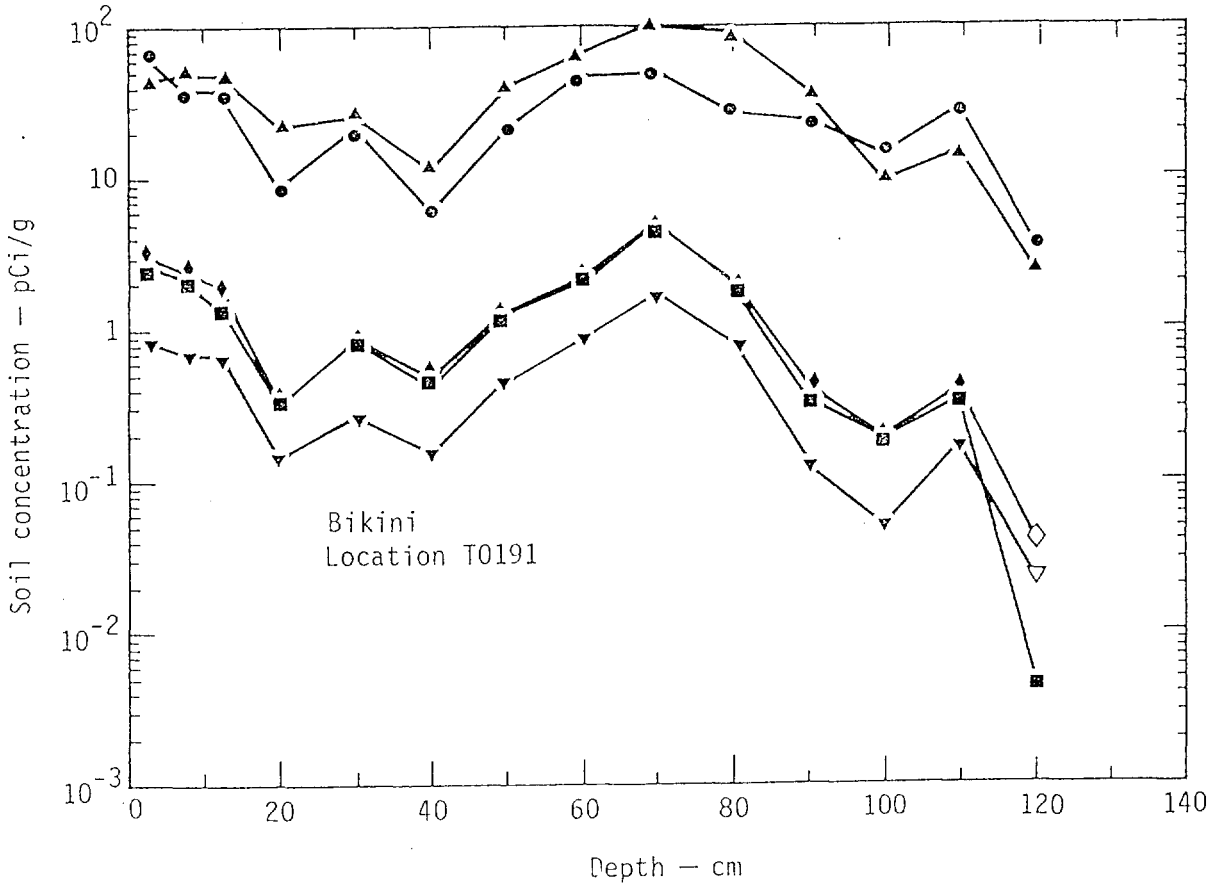

Bikini
Location T0071
Soil concentration — pCi/g
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70
Depth — cm

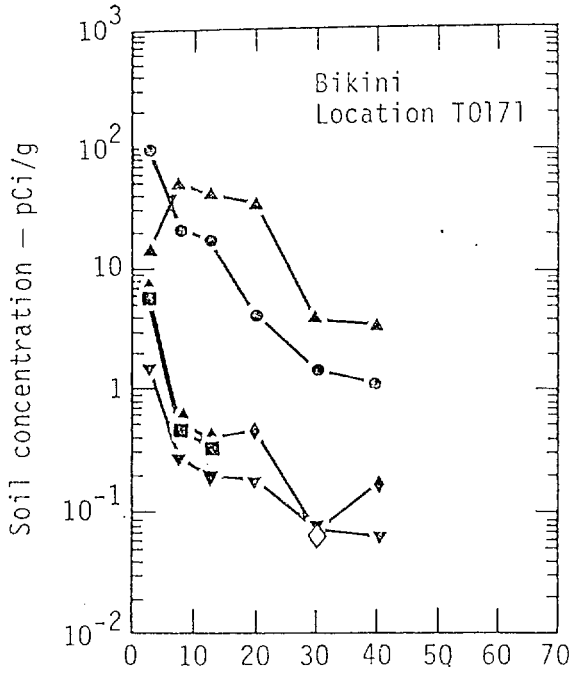

Bikini
Location T0081
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 110
Depth — cm

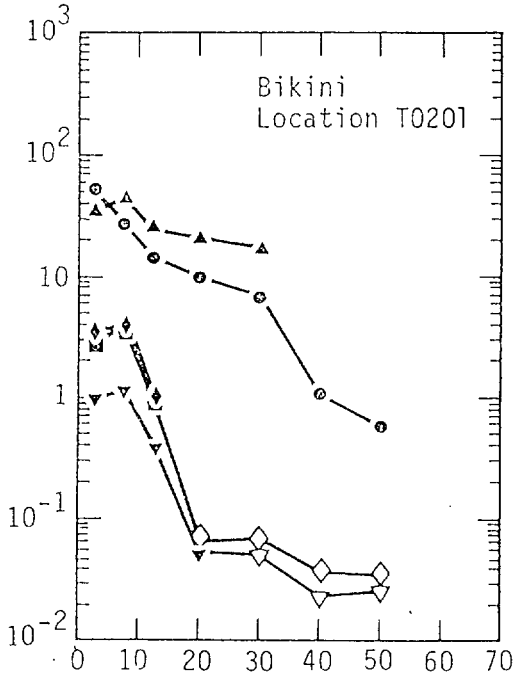

Bikini
Location T0091
Soil concentration — pCi/g
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70
Depth — cm

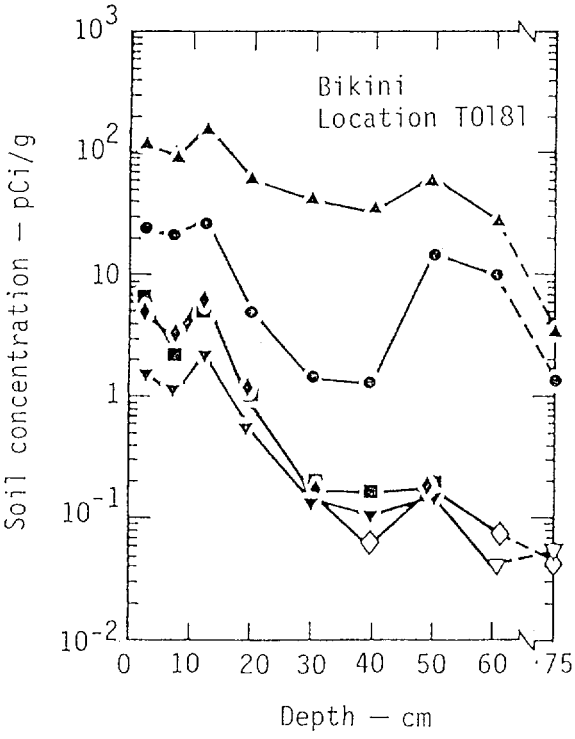

Bikini
Location T0101
Bikini
Location T0121
Bikini
Location T0111
Bikini
Location T0131
Soil concentration — pCi/g
Soil concentration — pCi/g
Depth — cm
Depth — cm

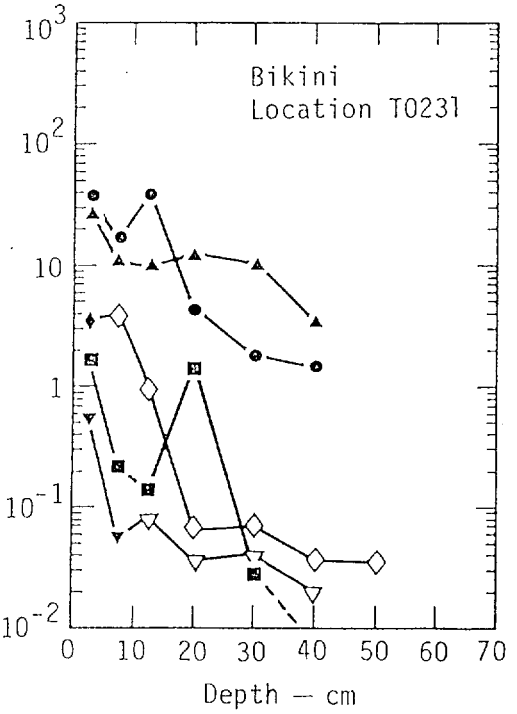

Bikini Location T0161
Soil concentration — pCi/g
10^3
10^2
10
1
10^{-1}
10^{-2}
0
20
40
60
80
100
120
140
160
180
Depth — cm

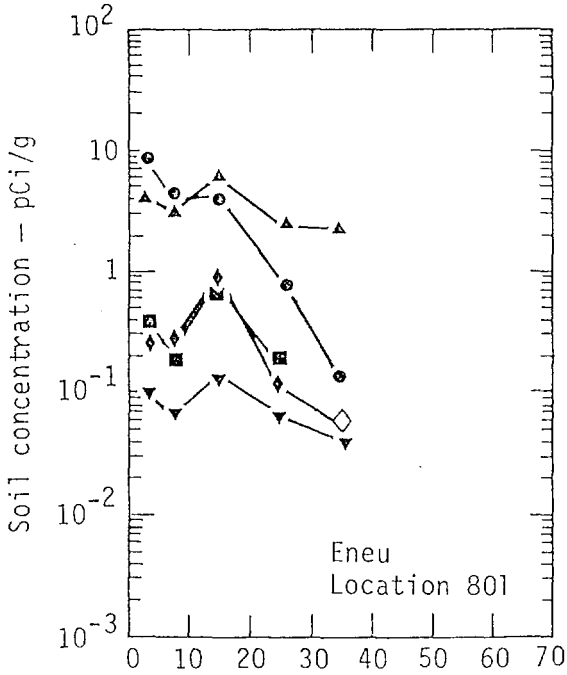

Soil concentration — pCi/g
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
Bikini
Location T0191
0
20
40
60
80
100
120
140
Depth — cm

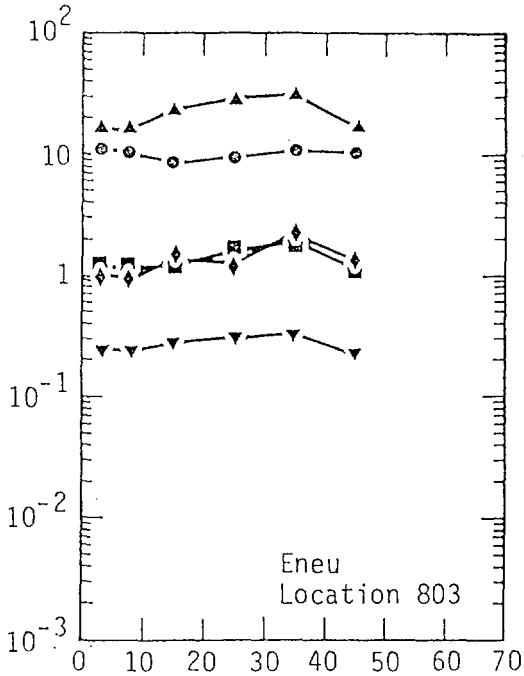

Bikini
Location T0171
Soil concentration — pCi/g
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70

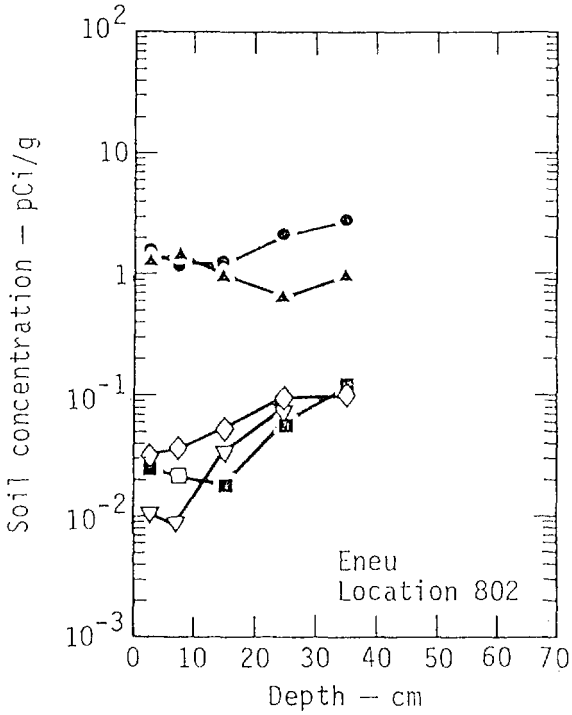

Bikini
Location T0201
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70

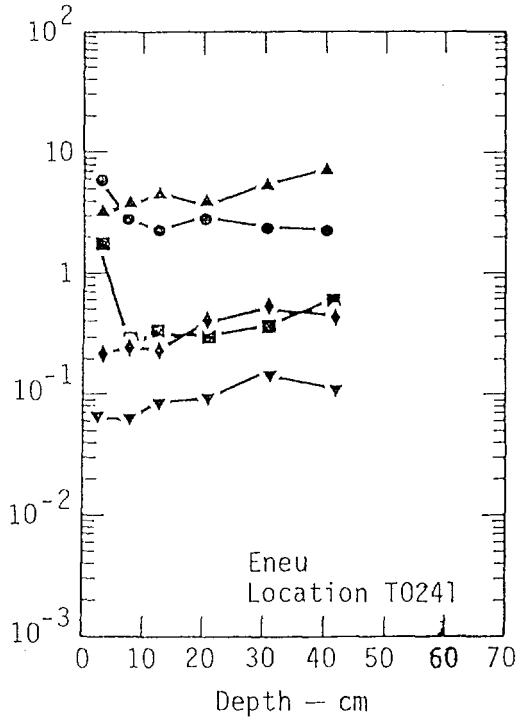

Bikini
Location T0181
Soil concentration — pCi/g
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 75
Depth — cm

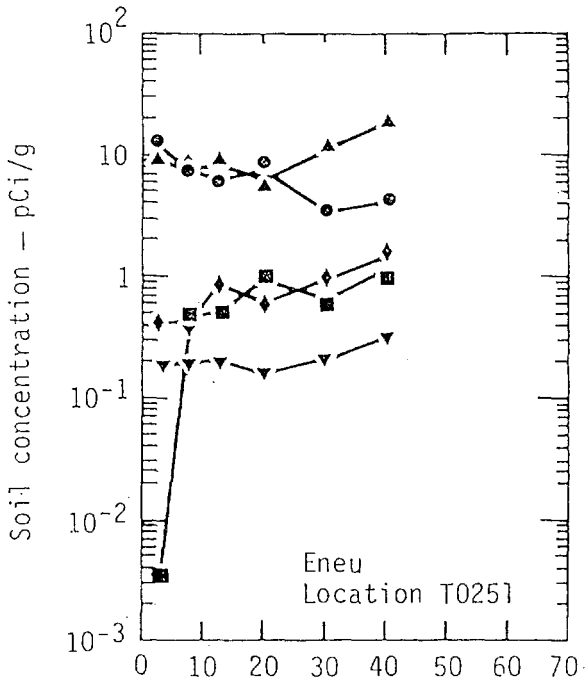

Bikini
Location T0231
10^3
10^2
10
1
10^{-1}
10^{-2}
0 10 20 30 40 50 60 70
Depth — cm

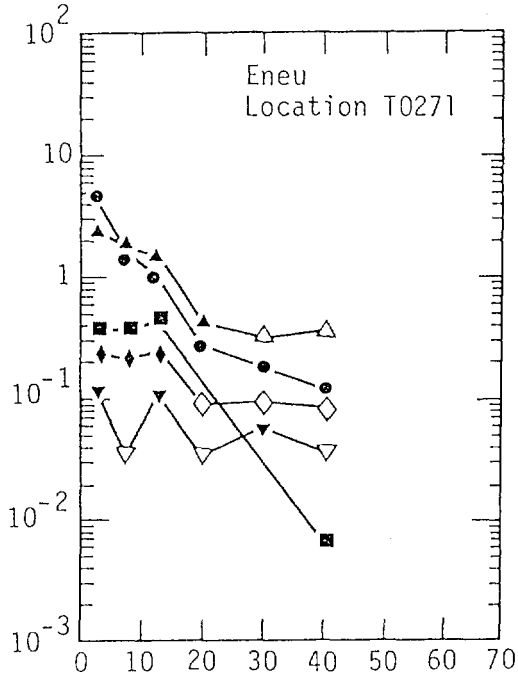

Soil concentration — pCi/g
Eneu
Location 801

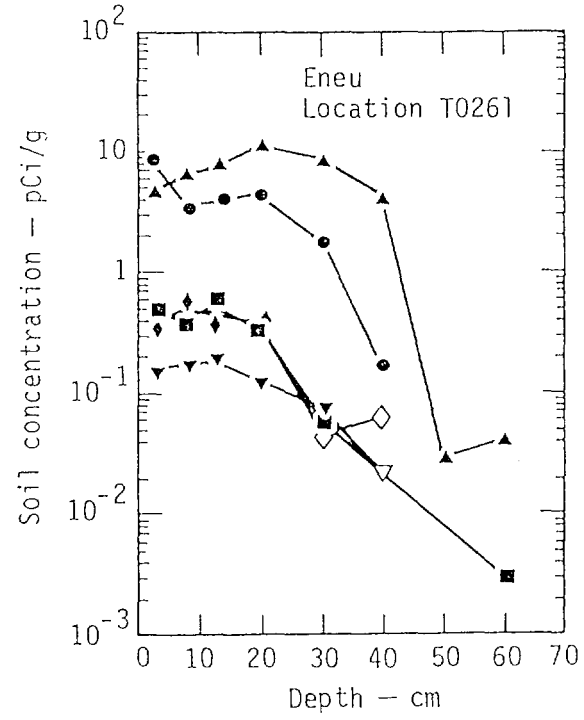

Eneu
Location 803

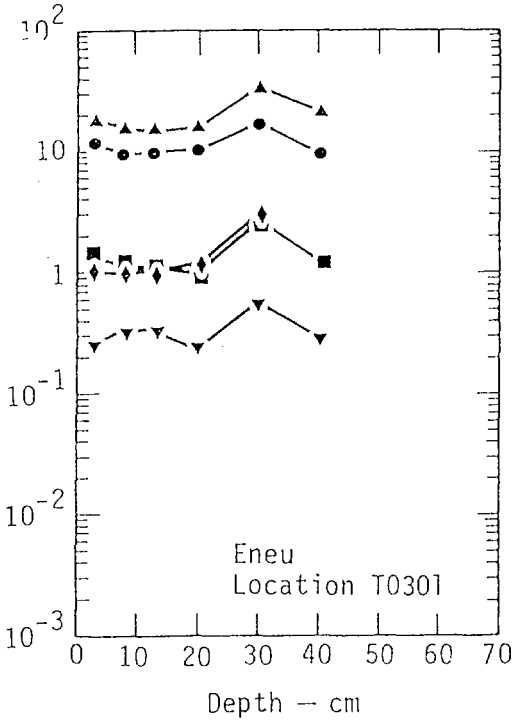

Soil concentration — pCi/g
Eneu
Location 802
Depth — cm


Eneu
Location T024I
Depth — cm


Soil concentration — pCi/g
Eneu
Location T025l


Eneu
Location T027l


Soil concentration — pCi/g
Eneu
Location T026l
Depth — cm


Eneu
Location T030l
Depth — cm

Appendix C. Geographical Distribution of Radioactivity in the Surface Soil (0 to 15 cm) of Bikini and Eneu Islands

The following maps present the concentrations of ^{60}Co, ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{240}Pu, and ^{241}Am (pCi/g dry weight) at the various samplings sites of the top 15 cm of soil on Bikini and Eneu Islands.

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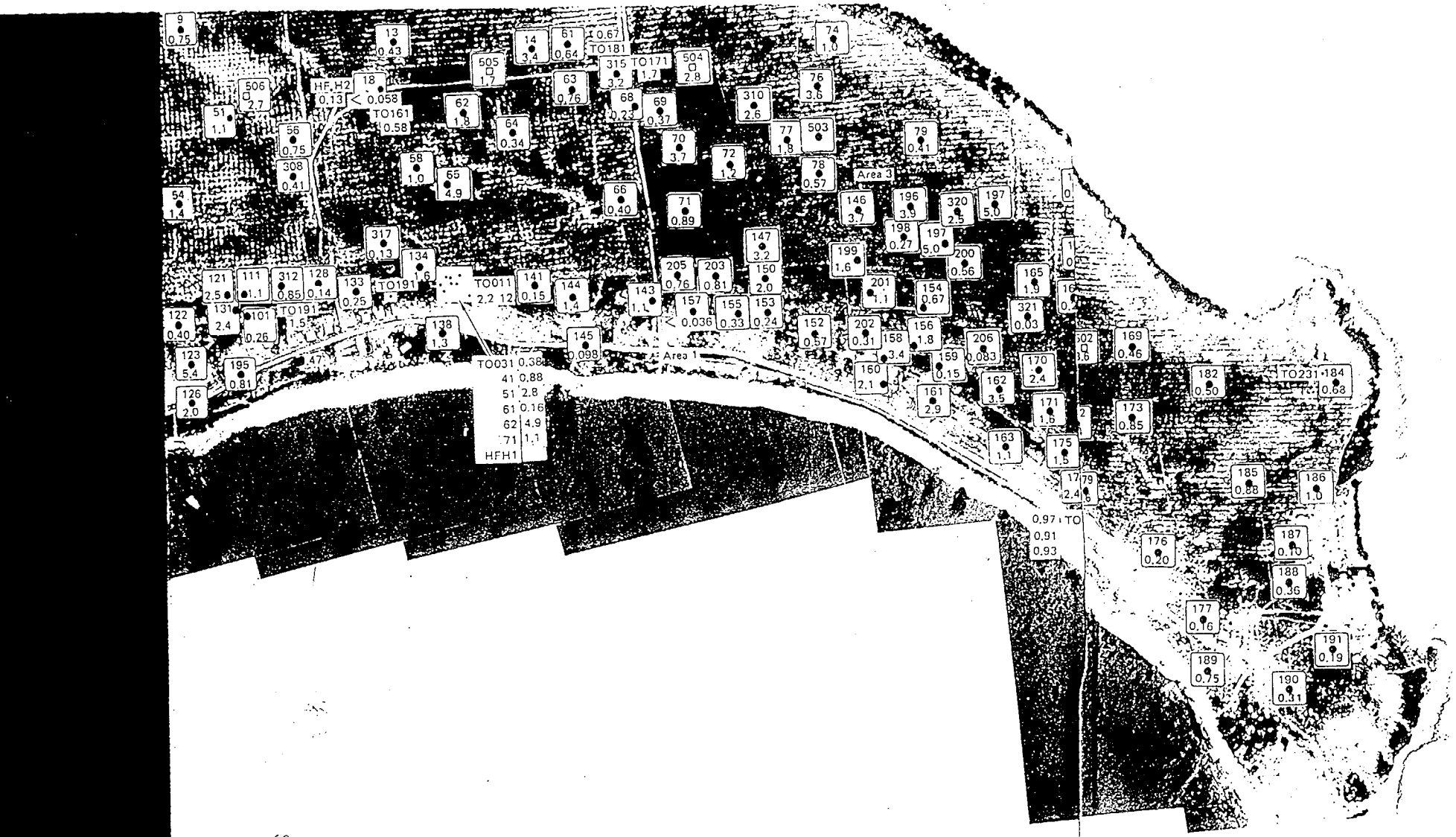
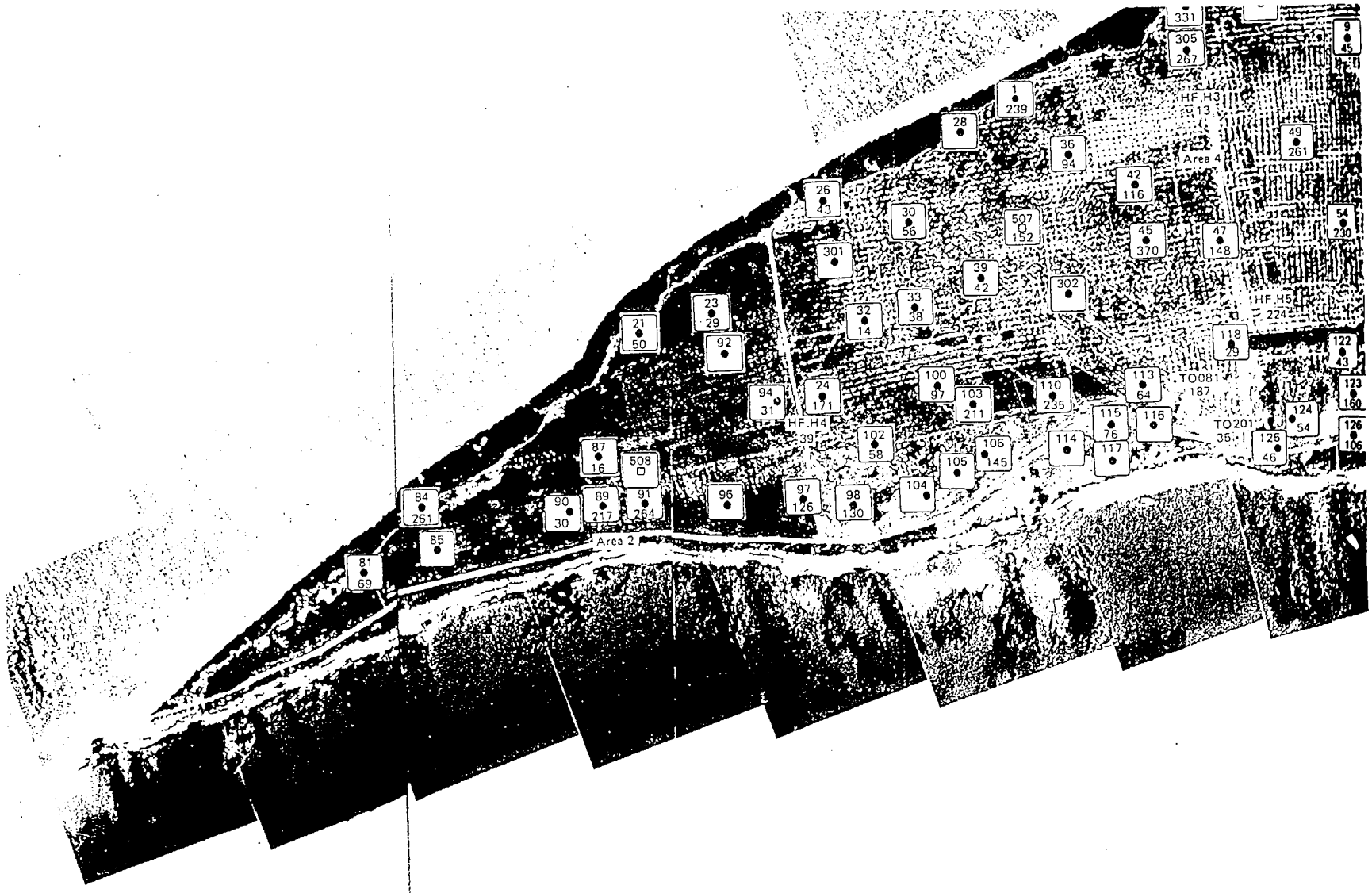
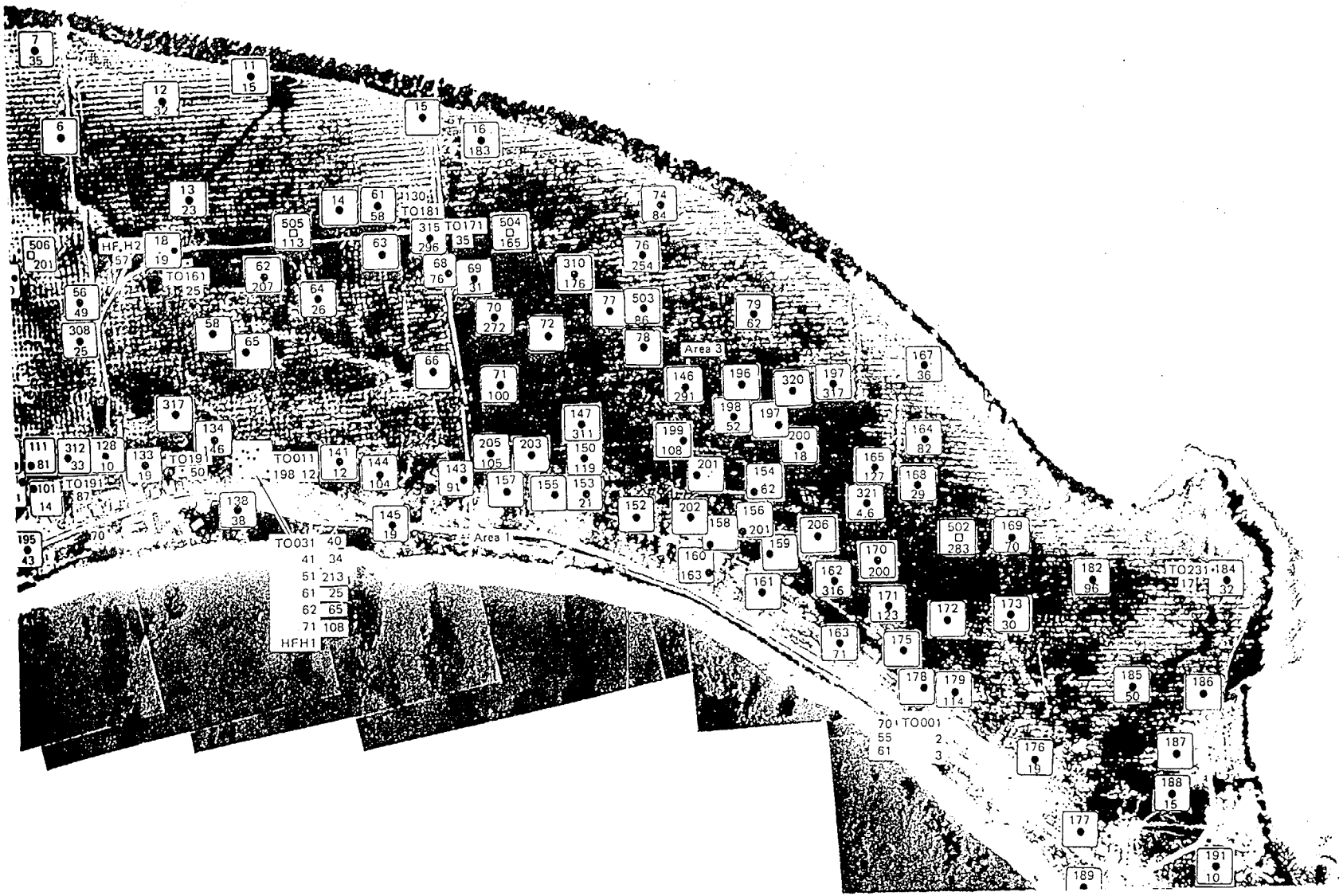


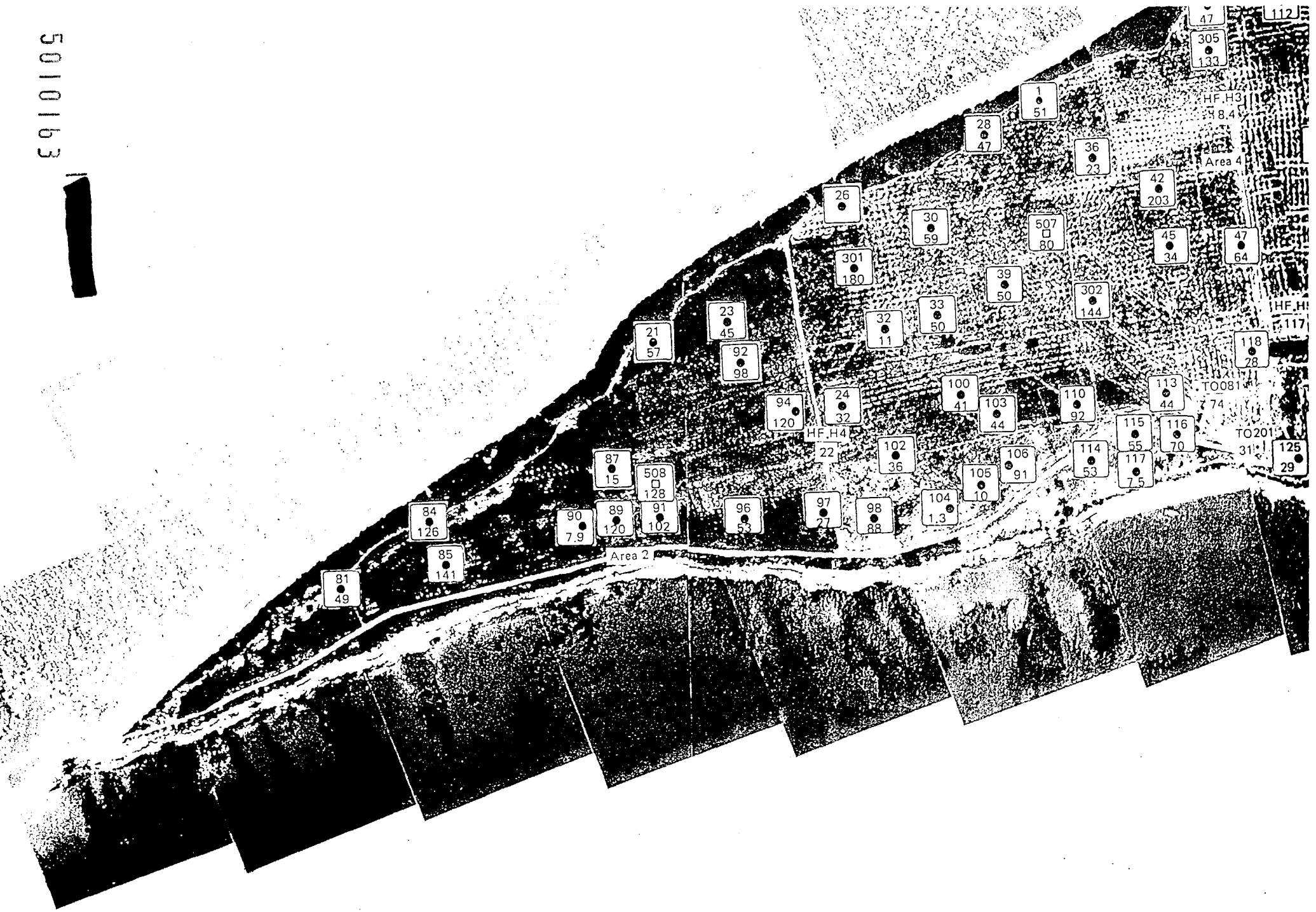
ni Island, ^{60}Co



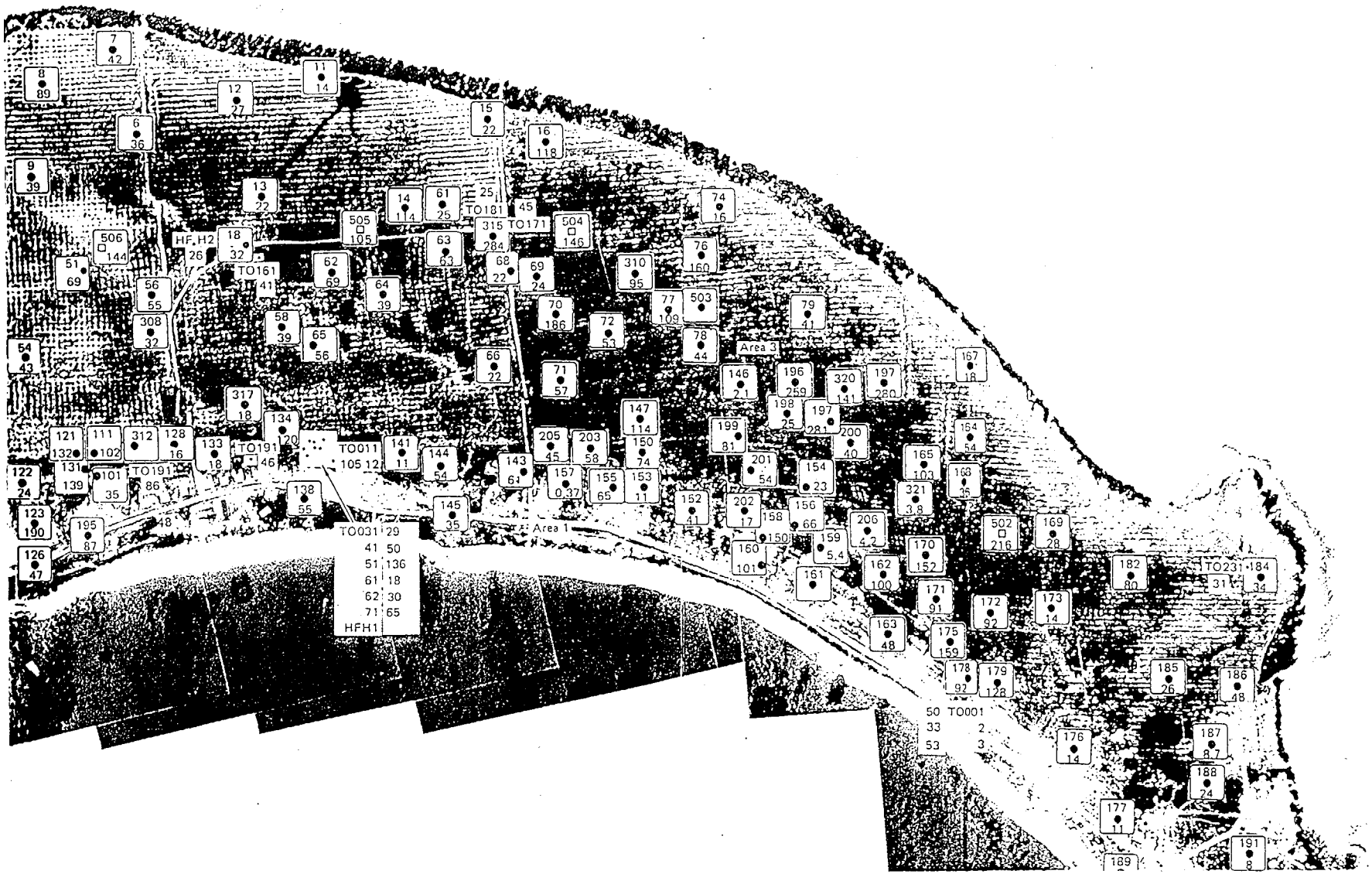
Bikini I

C-


Area 1
Area 3
HF,H2
TO031
TO011
TO019
TO191
TO161
TO181
TO171
TO001
TO231
HFH1

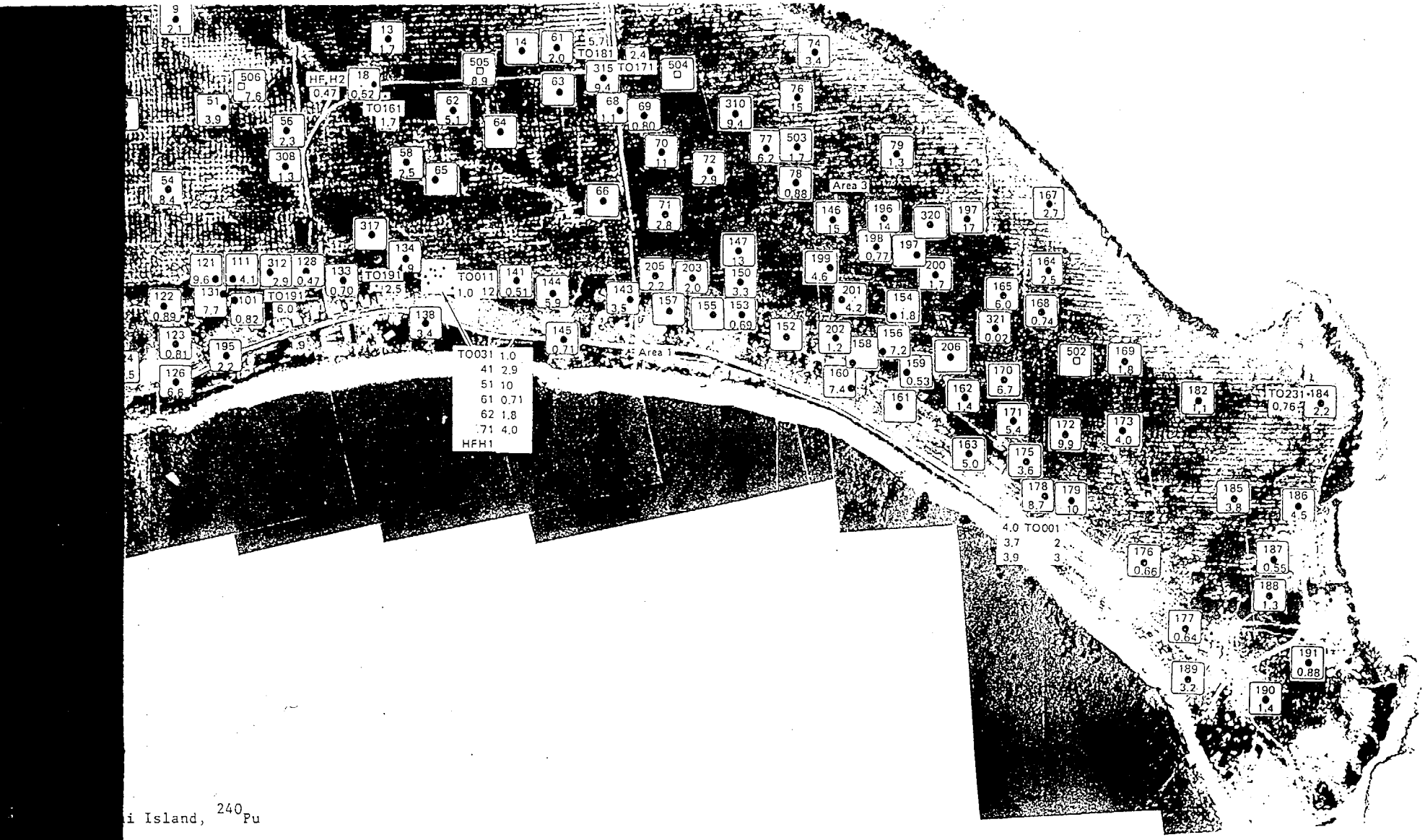


Biki

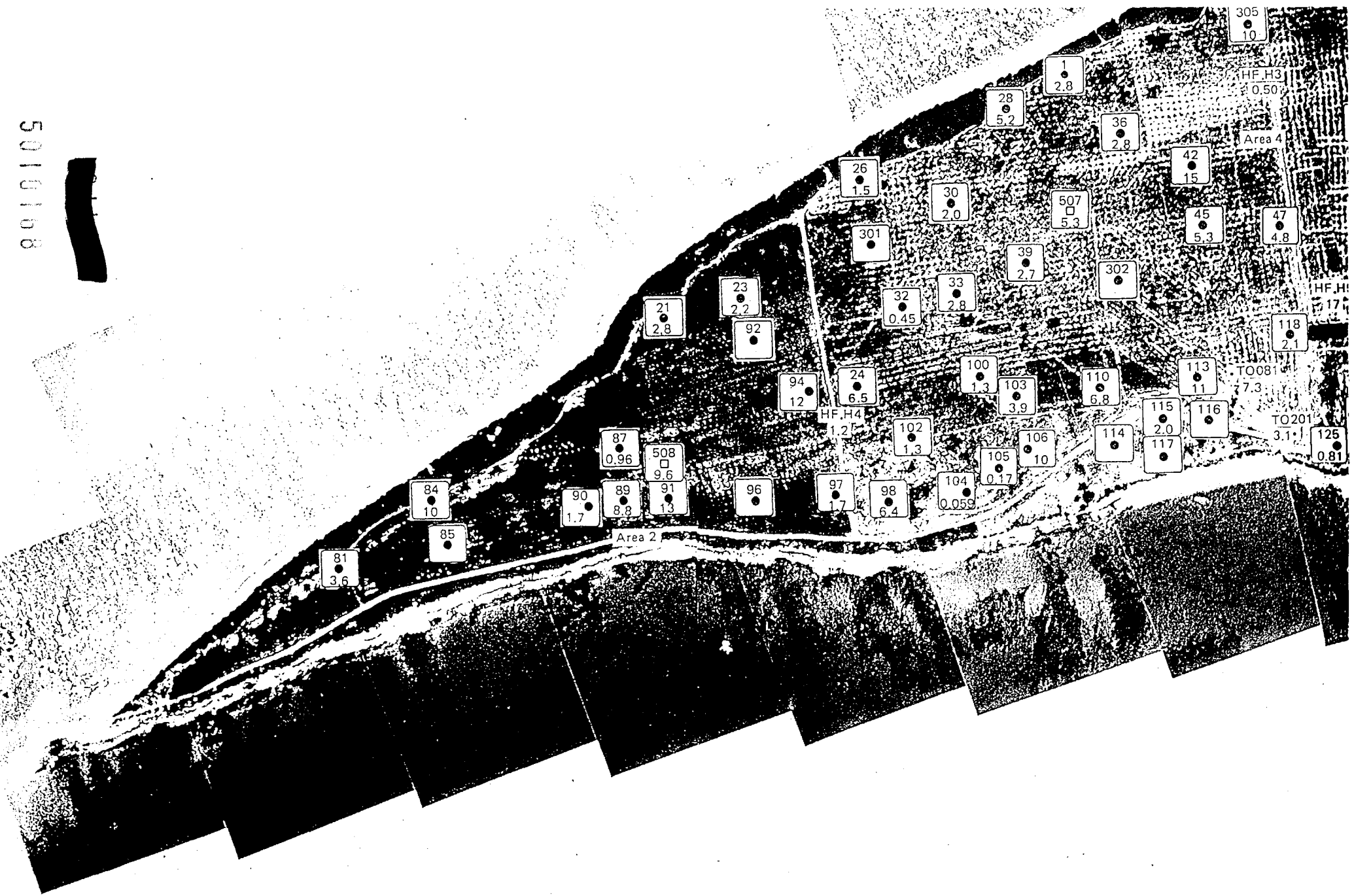

Area 1
Area 3
HF, H2
TO011
TO031
TO161
TO171
TO181
TO191
TO231
TO001
HFH1

Bikini Isla

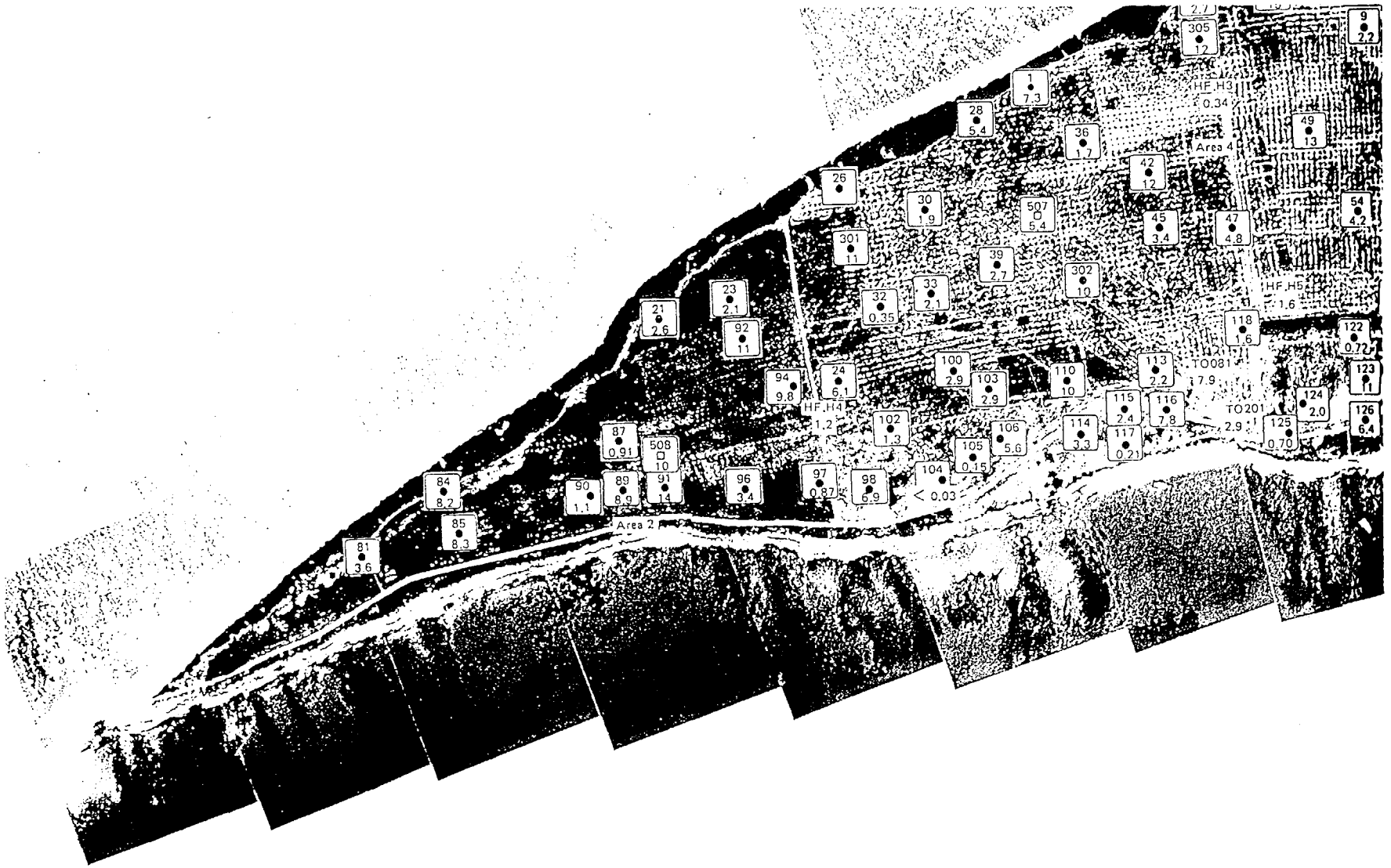

HF,H2
0.42
TO161
1.5
TO181
5.1
TO171
2.1
Area 3
TO191
TO011
7.7
TO031
0.90
41 2.5
51 9.1
61 0.64
62 1.6
71 3.5
HFH1
Area 1
TO001
TO231
0.68



i Island, ^{240}Pu


305
10
1
2.8
HF_H3
0.50
28
5.2
36
2.8
Area 4
42
15
26
1.5
30
2.0
507
5.3
45
5.3
47
4.8
301
39
2.7
302
HF_H
17
23
2.2
21
2.8
32
0.45
33
2.8
92
118
2.1
100
1.3
113
11
TO081
7.3
94
12
24
6.5
HF_H4
1.2
103
3.9
110
6.8
115
2.0
116
TO201
3.1
102
1.3
106
10
114
117
125
0.81
87
0.96
508
9.6
105
0.17
84
10
90
1.7
89
8.8
91
13
96
97
1.7
98
6.4
104
0.059
Area 2
85
81
3.6

Bik



Bikini Isl


Area 2
Area 1
TO031
TO181
TO171
TO161
TO191
TO011
TO231
TO001
HF, H2
HFH1
241 Am

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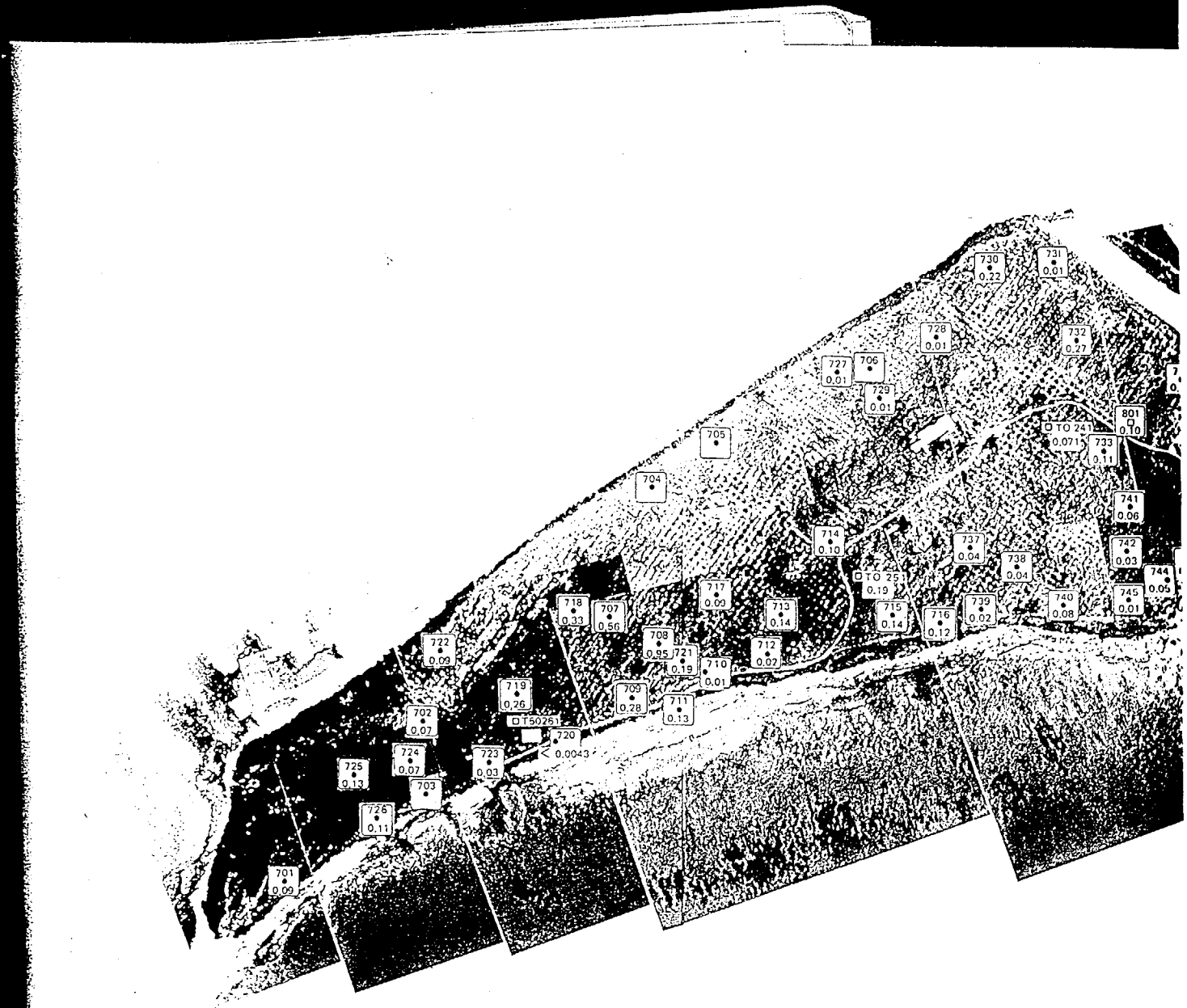
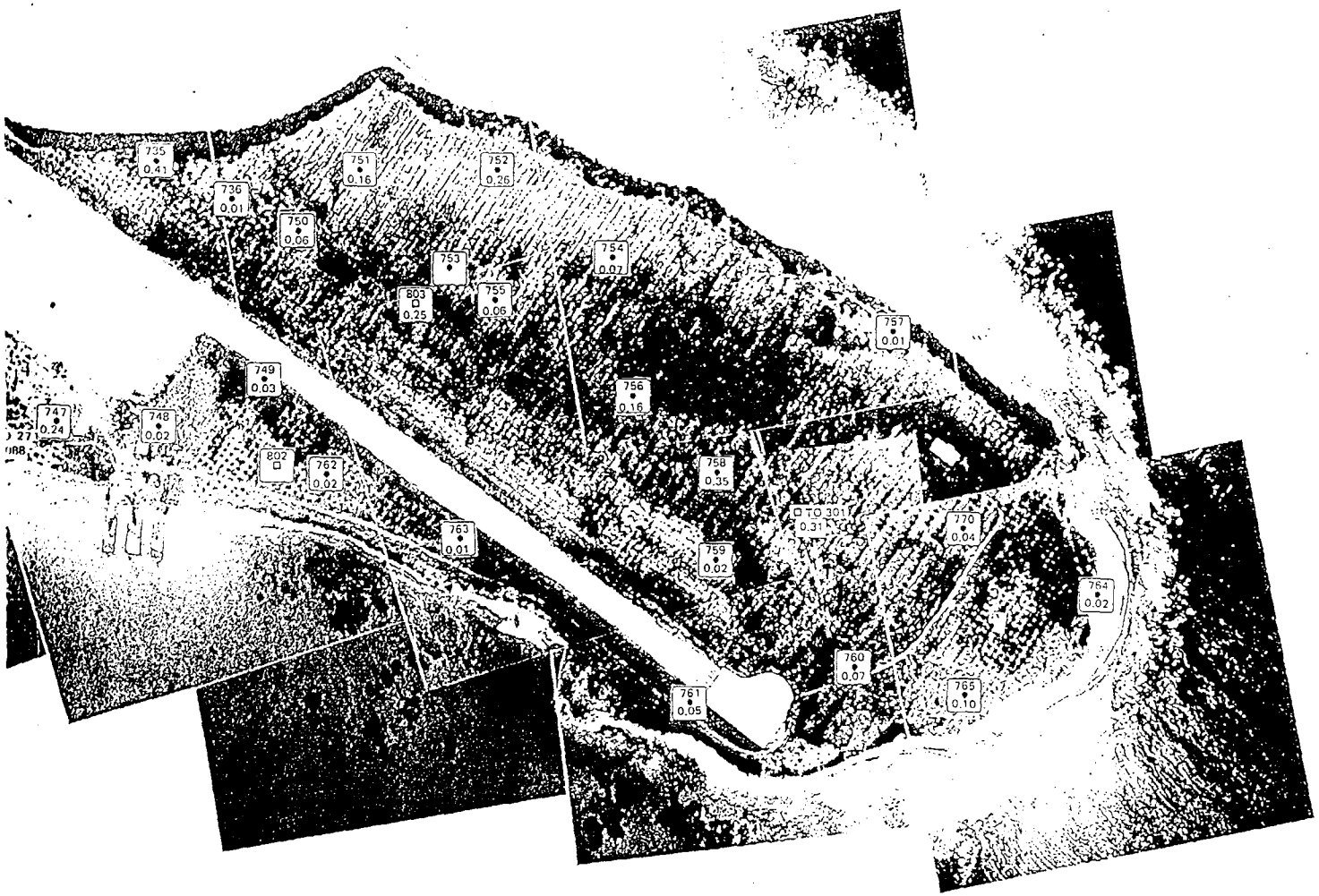
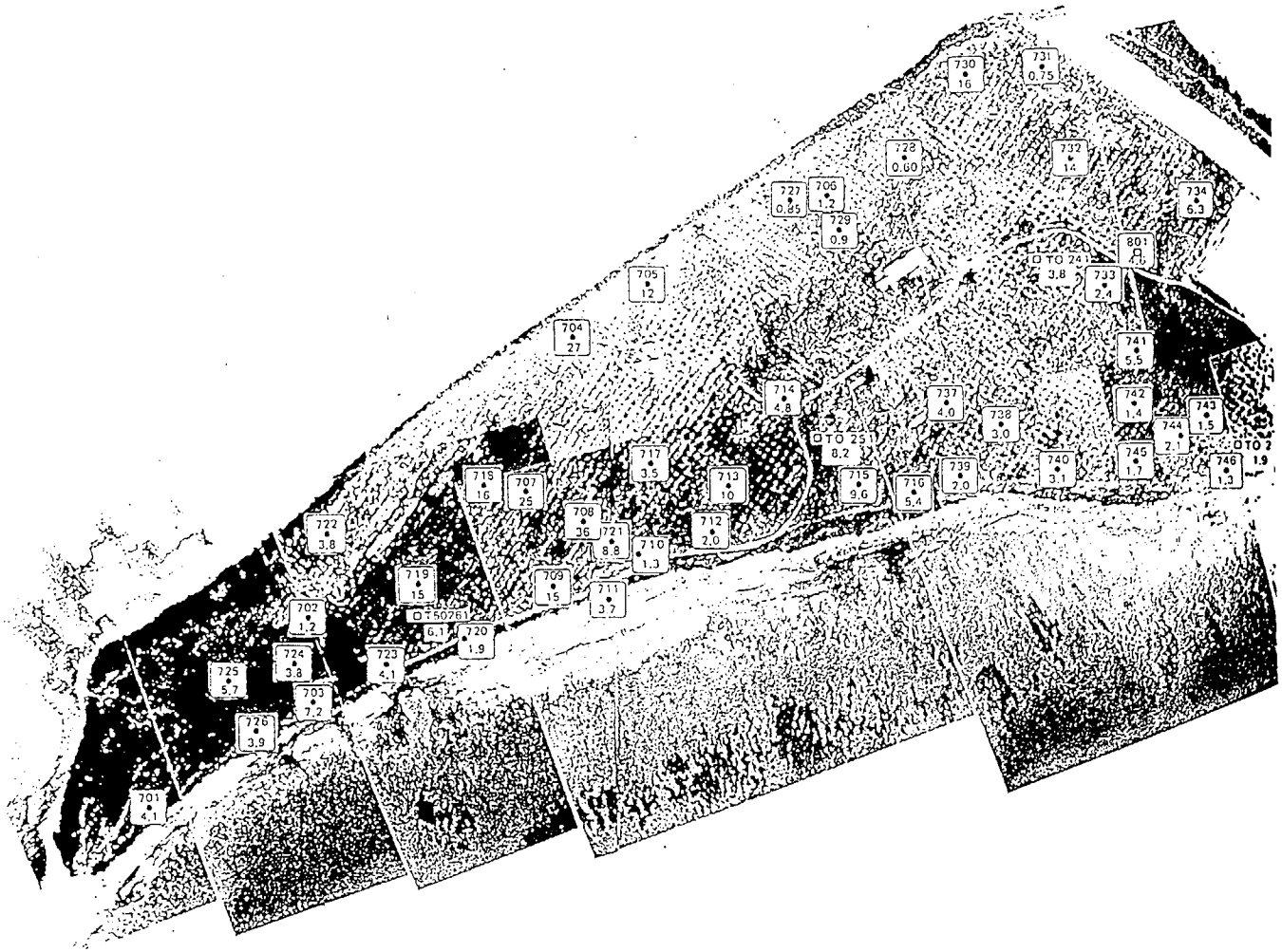

701 0.09
702 0.07
703
704
705
706
707 0.56
708 0.95
709 0.28
710 0.01
711 0.13
712 0.02
713 0.14
714 0.10
715 0.14
716 0.12
717 0.09
718 0.33
719 0.76
720 0.0043
721 0.19
722 0.09
723 0.03
724 0.07
725 0.13
726 0.11
727 0.01
728 0.01
729 0.01
730 0.22
731 0.01
732 0.27
733 0.11
737 0.04
738 0.01
739 0.02
740 0.08
741 0.06
742 0.03
744 0.09
745 0.01
801 0.10
TO 24 0.071
TO 25 0.19
T50251

En



land, ^{60}Co

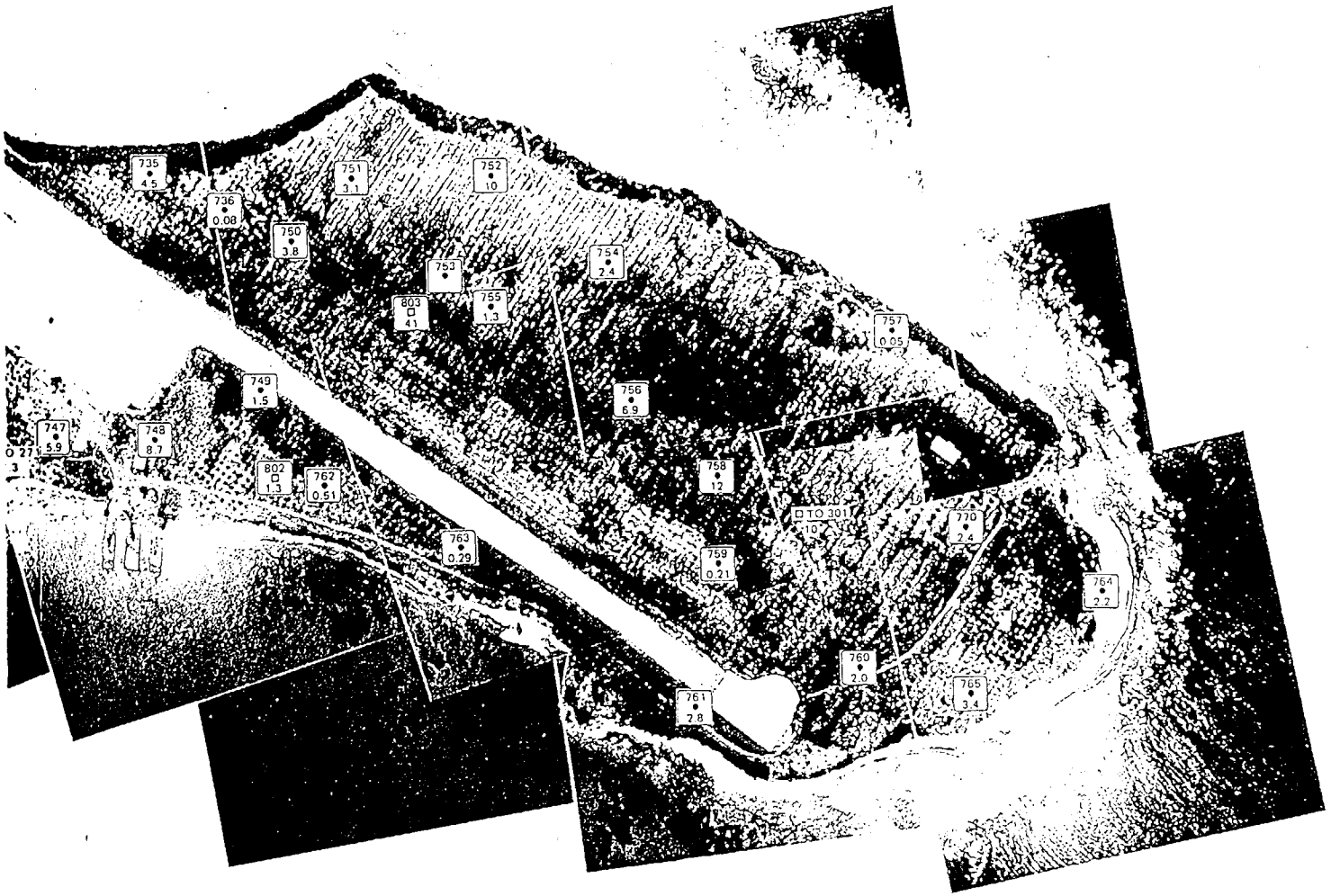
C-9



Eneu Islan

C-1

735 18
748 3.0
736 0.36
749 1.7
802 1.3
750 2.8
762 1.5
751 10
803 19
753 18
763 0.85
755 4.6
752 10
754 13
756 34
761 8.1
759 0.9
758 22
D TO 301 16
760 3.7
757 0.9
770 5.8
765 6.4
764 3.8

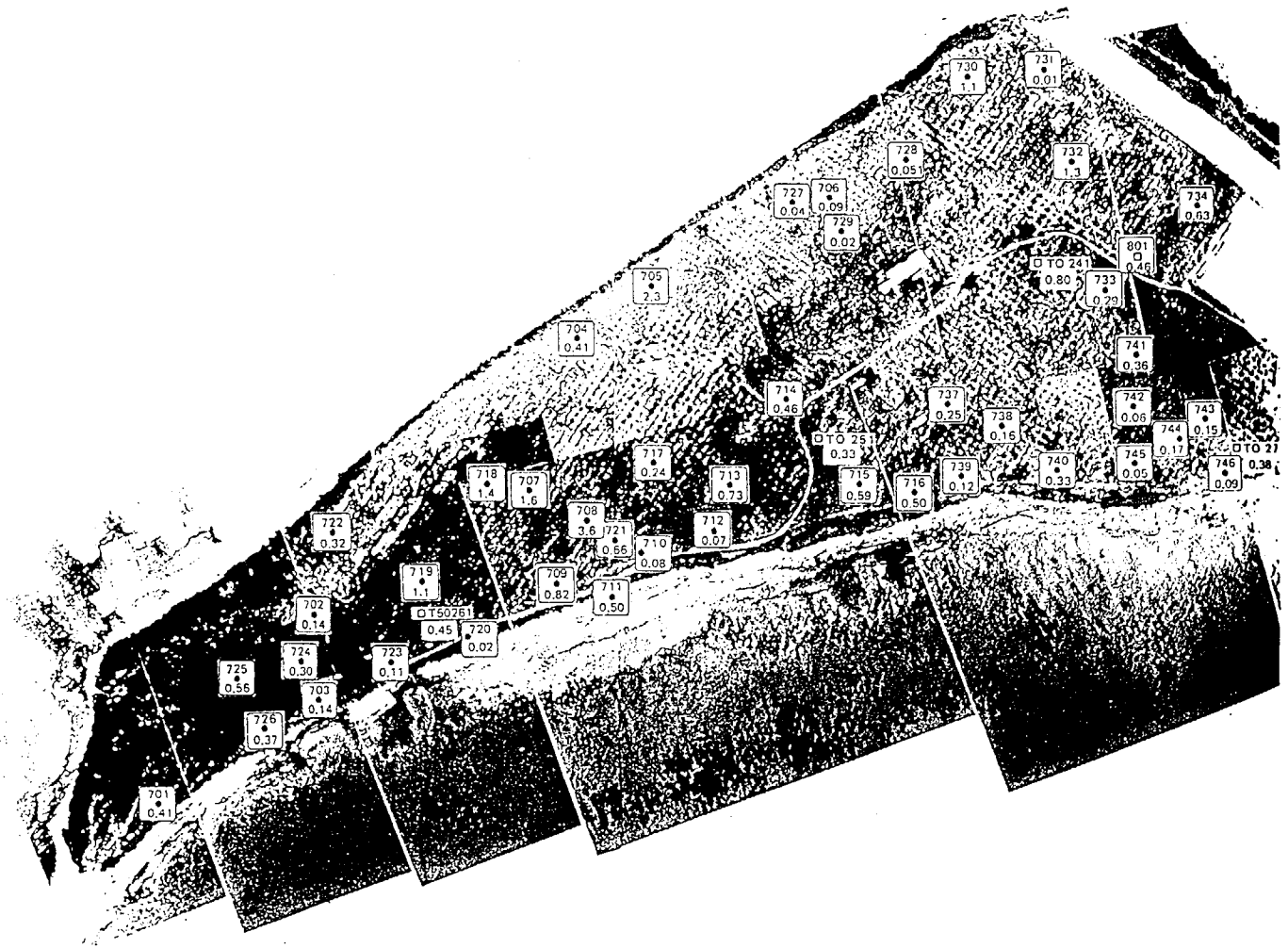


and, ^{137}Cs

C-11

701 1.7
702 2.8
703
704
705
706
707 29
708 28
709 12
710 0.74
711 2.0
712 2.2
713 5.1
714 6.6
715 5.1
716 5.1
717 5.4
718 11
719 15
720 1.0
721 9.5
722 6.4
723 5.7
724 4.6
725 3.3
726 2.2
727 0.57
728 0.29
729 0.36
730 4.4
731 0.39
732 8.8
733 4.3
737 3.0
738 4.7
739 2.1
740 6.6
741 4.9
742 1.0
744 3.9
745 2.2
801 5.6
TO 24 3.8
TO 25 8.7
TSO261 5.1

Enc



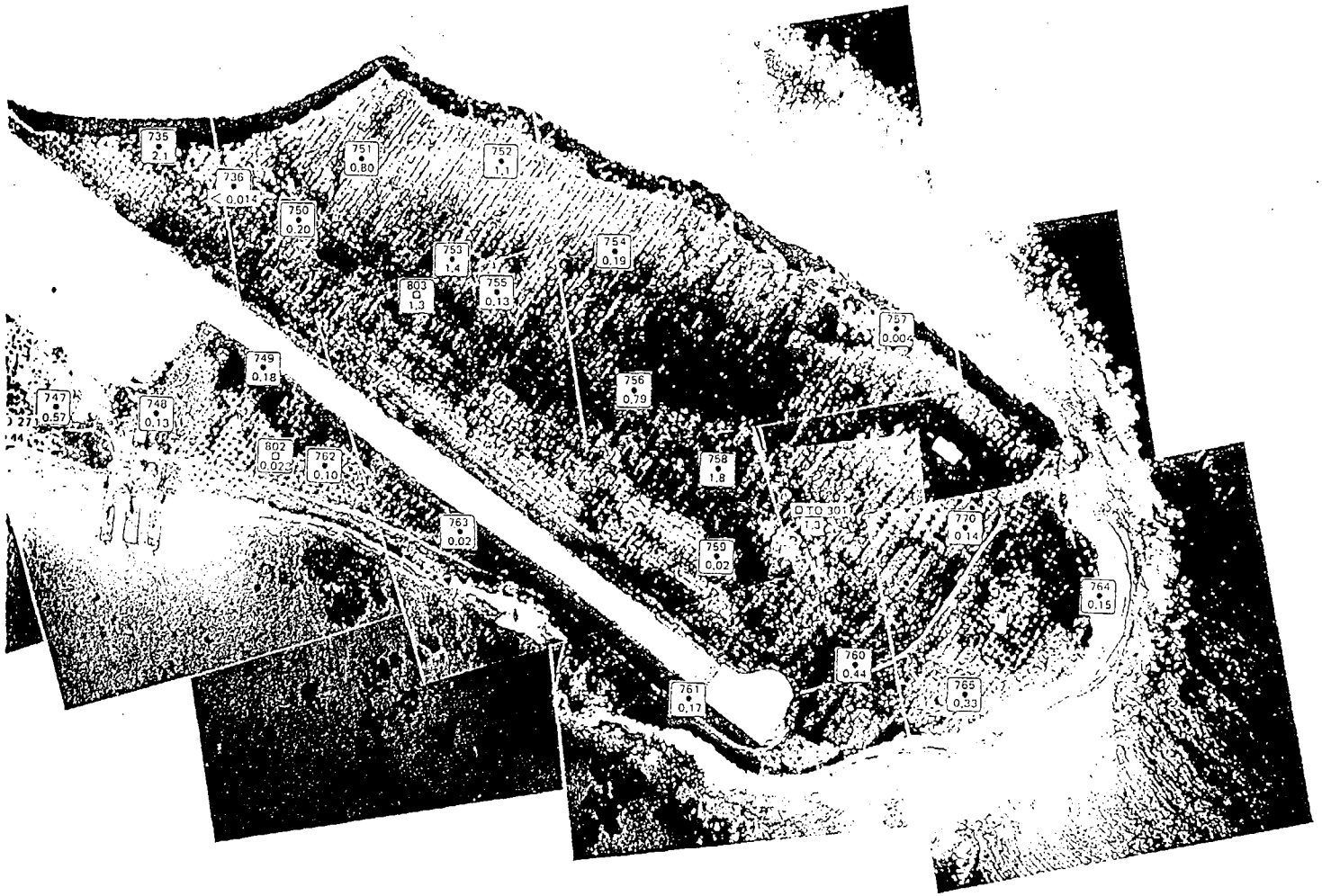
Eneu Islan

735
1.0
736
< 0.0014
750
0.19
751
0.1
752
1.0
753
1.3
754
0.15
755
0.13
756
0.23
757
0.005
758
1.8
759
0.003
760
0.2
761
0.15
762
0.001
763
0.02
764
0.14
765
0.11
766
0.2
767
0.01
768
1.2
769
0.16
770
0.13
748
0.12

5010178

744 0.22
741 0.35
742 0.06
745 0.06
800 0.5
733 0.30
TO 24 0.94
732 1.4
731 0.008
740 0.13
730 2
736 0.18
737 0.27
739 0.13
728 0.052
716 0.56
TO 25 0.36
715 0.65
706 0.01
729 0.02
727 0.05
714 0.53
713 0.85
712 0.09
705 2.5
717 0.4
710 0.10
721 0.76
711 0.65
704 0.47
708 4.1
709 0.95
707 8
718 1.5
720 0.02
T 5075 0.53
719 1.1
722 0.14
727 0.35
702 0.18
724 0.36
703 0.16
770 0.46
775 0.63
701 0.40

5010179



nd, ^{240}Pu

-13

Ineu Isla

C-

5010181


735 1.7
736 <0.02
748 <0.02
749 0.11
762 <0.05
750 0.19
751 0.66
803 1.1
753 1.3
755 0.14
752 1.2
763 <0.05
754 0.13
756 0.71
761 0.21
759 <0.05
758 1.5
760 0.30
757 <0.04
765 0.30
770 0.11
764 0.19

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UCRL-51879, Part 4

EVALUATION OF THE RADIOLOGICAL QUALITY OF THE WATER ON BIKINI AND ENEU ISLANDS IN 1975: DOSE ASSESSMENT BASED ON INITIAL SAMPLING

V. E. Noshkin, W. L. Robison,
K. M. Wong, and R. J. Eagle

January 21, 1977

Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48

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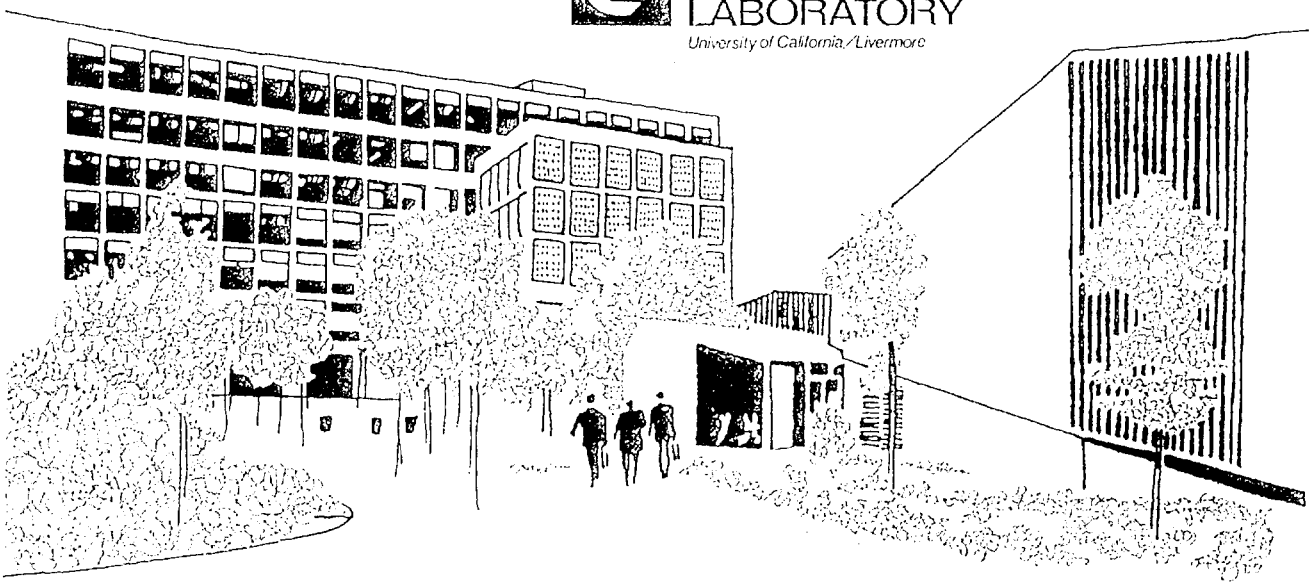

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